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SECTION 19

WIRING DESIGN FOR COMMERCIAL AND INDUSTRIAL BUILDINGS

John Dagenhart, P. E.

Professional Engineer, Clapp Research Associates. P. C.

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19.1 BASIC INSTALLATION RULES AND INSPECTION

Codes (Definitions). The *National Electrical Code* (NEC)*

The *National Electrical Safety Code* (NESC) establishes the basic standards of electric supply system design and installation for utility-owned conductors and equipment in the United States. It is also revised periodically by a committee drawn from utility groups, industries, state and federal regulators, insurance groups, organized labor, and other interested parties. Its secretariat is the Institute of Electrical and Electronics Engineers; the NESC is American National Standard ANSI C2. The NEC oversees supply and communication wiring that are in and on consumer-owned buildings but not an integral part of a generating plant, substation, or control center. The NEC does not cover communication utility wiring, nor does it cover electric utility generation, transmission, or distribution system wiring. The NESC covers the latter systems. The NESC also covers similar systems under the control of qualified persons, such as those associated with large industrial complexes. In recent years, the provisions of the NESC relating to underground wiring have become increasingly applicable in commercial complexes as extremely large commercial complexes have become more frequent. Some of the latter systems are not unlike those utility systems found in small towns or compact subdivisions.

Lists of Inspected Electrical Equipment and Appliances are issued yearly by the *Underwriters' Laboratories, Inc.* *Electrical Testing Laboratories, Inc.*, *Factory Mutual Research Corp.*, and *MET Electrical Testing Company, Inc.* are other testing laboratories that function as third-party certifiers of the basic safety of manufactured products used in electrical work. One function of the laboratories

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Establishes the standards of wiring design and installation practice for consumer-owned wiring and equipment in the United States. Its rules are written to protect the public from fire and life hazards. It is revised periodically by a committee drawn from industry associations, insurance groups, organized labor, and representatives of municipalities. It is sponsored by the National Fire Protection Association, and approved by the American National Standards Institute as ANSI C1. It forms the basis of the vast majority of municipal electrical wiring ordinances, which adopt successive editions of the Code as issued.

is to examine and pass on electrical materials, fittings, and appliances in order to determine if they comply with the standard-test specifications set up by these laboratories.

Legal Status of the Code. The rules in the NEC are enforced by being incorporated in ordinances passed by various cities and towns, covering the installation of electric wiring. The Occupational Safety and Health Administration (OSHA) requires that all new electrical installations conform to all the rules of the NEC. The NESC is adopted by state utilities commissions and is referred to by the NEC for some high-voltage applications.

When installing any electrical equipment, first ascertain whether local installation rules in the form of ordinances are enforced in the community. If so, follow such rules; if none exists, follow the requirements of NEC.

Editions. Where reference is made in this section to installation rules, the 1996 edition of NEC or 1997 NESC is used as a basis.

Code Not a Design Manual. Design of an installation in accordance with the Code minimizes fire and accident hazards but does not guarantee satisfactory or efficient operation of the system. Other design standards are necessary to accomplish the latter purposes.

License. In many areas the installation of electric wiring is controlled by city, county, or state license, often combined with installation rules.

Rules of Electric Service Companies. Electric lighting and power companies generally issue certain rules of their own, based to a large extent on peculiar requirements which are necessary in order to give the best possible service to the greatest number of customers and on NESC requirements.

These rules are concerned mostly with matters of distribution engineering. They relate to locations and details of service entrance, provision for meters, the kind of electricity furnished by the company, its frequency and voltage, the types and sizes of motors, rules in connection with starting characteristics of such motors, and similar matters.

The electric-service company usually supplies copies of its rules at no charge.

Inspection. Every electrical installation should be inspected wherever an experienced inspector is available to ensure that it complies with local and NEC rules. Such inspection is usually mandatory in cities having electrical ordinances. In some areas the fire underwriters maintain inspectors who check electrical wiring, while in others the municipality makes a check through its electrical inspectors. Where inspection is not mandatory, it is always advisable to request the most convenient fire underwriters' bureau to make the necessary inspection.

Federal and state buildings usually require inspection by authorized federal or state inspectors. In these instances inspection includes not only safety considerations but the requirements of the particular job specifications. Other inspection may be required but it is often waived. OSHA compliance officers do make inspections of existing electrical systems at any time.

19.2 METHODS OF WIRING

Wiring Methods Classified. The discussion of wiring methods in this section relates to *interior circuits for light, heat, and power* and does not cover signaling or communication systems.

Numerous methods of wiring are authorized by NEC, most of them used to a greater or lesser extent in commercial and industrial buildings. Those of interest can be grouped as follows:

1. Raceways for general use
 - a. Rigid-metal conduit
 - b. Intermediate-metal conduit (IMC)
 - c. Electric-metallic tubing (EMT)

- d.* Nonmetallic conduit
 - e.* Surface raceways
 - f.* Flexible metallic and nonmetallic conduit
 - g.* Gutters
- 2. Cable-assembly systems for general use
 - a.* Nonmetallic sheathed cable
 - b.* Underground feeder and branch-circuit cable
 - c.* Metal-clad cable (armored cable)
 - d.* Mineral-insulated metal-sheathed cable (MIMS)
 - e.* Messenger-supported wiring
 - f.* Nonmetallic-sheathed cable (NM, NMC, NMS)
 - g.* Power and control cable (TC)
 - h.* Armored cable
- 3. Conductor systems for general use
 - a.* Open wiring on insulators
 - b.* Concealed knob and tube wiring (only as permitted in NEC Sec. 394)
- 4. Cable-assembly systems for limited use
 - a.* Service-entrance cable
 - b.* Nonmetallic extensions
 - c.* Integrated gas spacer cable (IGS)
 - d.* Medium-voltage cable (MV)
 - e.* Flat conductor cable (FCC)
- 5. Raceway systems for limited use
 - a.* Flexible-metal conduit and flexible-metal tubing
 - b.* Liquidtight-flexible-metal conduit and liquidtight flexible nonmetallic conduit
 - c.* Underfloor raceway
 - d.* Cellular-metal-floor or cellular-concrete-floor raceway
 - e.* Wireways
 - f.* Cable trays
- 6. Special systems
 - a.* Busways
 - b.* Cable bus
 - c.* Multioutlet assemblies
 - d.* Electrical floor assemblies
 - e.* Flat cable assemblies

Installation Methods. Requirements to be met in installing each of the foregoing systems are found in the current edition of the NEC. The requirements are specific and detailed and change somewhat as the art progresses; hence reference should be made to the Code for the exact circumstances under which each system is permitted or prohibited, together with the precise rules to be followed in installation.

The discussion in the following paragraphs compares the systems generally and indicates the major limitations on use of each.

19.3 TYPES OF CONDUCTOR

General Provisions Applying to All Wiring Systems. The types of wiring discussed may be used for voltages up to 2000 V unless otherwise indicated. Each type of insulated conductor is approved for certain uses and has a maximum operating temperature. If this is exceeded, the

insulation is subject to deterioration. In recent years, conductors with asbestos insulation, formerly used for high-temperature operations, have been removed from the tables of conductor applications and insulations (see Table 19-1). Each conductor size has a maximum current-carrying capacity, depending on type of insulation and conditions of use. These ratings should not be exceeded (see Tables 19-2A through 19-2E and Fig. 19-1 for ratings and underground conduit systems). Conductors may be used in multiple usually in large sizes only (sizes 1/0 and larger, see NEC Sec. 310-4).

Conductors of more than 600 V should not occupy the same enclosure as conductors carrying less than 600 V, but conductors of different light and power systems of less than 600 V may be grouped together in one enclosure if all are insulated for the maximum voltage encountered. In general, communication circuits should not occupy the same enclosure with light and power wiring.

Boxes or fittings must be installed at all outlets, at switch or junction points of raceway or cable systems, and at each outlet and switch point of concealed knob and tube work.

Provisions Applying to All Raceway Systems. The number of conductors permitted in each size and type of raceway is definitely limited to provide ready installation and withdrawal. For conduit and EMT, see Table 19-3. Raceways, except surface-metal molding, must be installed as complete empty systems, the conductors being drawn in later. Conductors must be continuous from outlet to outlet without splice, except in auxiliary gutters and wireways.

Conductors of No. 8 American wire gauge (AWG) and larger must be stranded. Raceways must be continuous from outlet to outlet and from fitting to fitting and shall be securely fastened in place. Conductors and cables exposed to the sun must be sunlight resistant (see NEC Article 310.8(D)).

All conductors of a circuit operating on ac, if in metallic raceway, should be run in one enclosure to avoid inductive overheating. If, owing to capacity, not all conductors can be installed in one enclosure, each raceway used should contain a complete circuit (one conductor from each phase).

Rigid-Metal Conduit, Intermediate-Metal Conduit, and Electrical Metallic Tubing. These systems are systems generally employed where wires are to be installed in raceways. Both conduit and tubing may be buried in concrete fills or may be installed exposed. Wiring installed in conduit is approved for practically all classes of buildings and for voltages both above and below 600 V. Certain restrictions are placed on the use of tubing.

Metal conduit consists of standard-weight steel pipe (preferably either galvanized or cadmium-plated, although it may be black-enameled for use indoors and where not subject to severe corrosive influences) or of aluminum. Electrical metallic tubing has the same internal diameter as conduit but a thinner wall of higher-quality steel.

Note on Tables 19-2A through 19-2E: Use of conductors with higher operating temperatures. Where the room temperature is within 10°C of the maximum allowable operating temperature of the insulation, it is desirable to use an insulation with a higher maximum allowable operating temperature.

Fittings and connectors used with conduit may be threaded or threadless. Electrical metallic tubing fittings are usually threadless.

Nonmetallic rigid conduits, in approximately the same dimensions as rigid-metal conduits, are also a general-use raceway. Some restrictions are imposed, affecting particularly installations exposed to possible mechanical injury. Grounding continuity is provided by an additional grounding conductor pulled into the raceway with the circuit conductors or as part of a cable assembly.

Nonmetallic polyvinyl chloride (PVC) rigid conduits are commonly assembled with matching fittings by adhesives. Field bends are made by softening the plastic in a hot airstream of several hundred degrees from an electric heater-blower.

Nonmetallic PVC raceways of relatively flexible construction and with conductor already drawn in are used for direct burial in airport, highway, parkway, and similar installations.

Polyvinyl chloride and fiber conduits are extensively used in underground distribution. They may be installed directly in earth or encased in concrete envelopes.

TABLE 19-1 Conductor Application and Insulations

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of insulation											
					AWG or kcmil	mm	mils	Outer Covering ^a								
Fluorinated ethylene propylene	FEP or FEPB	90°C 194°F	Dry and damp locations	Fluorinated ethylene propylene	14–10	0.51	20	None								
		200°C 392°F	Dry locations—special applications ^b	Fluorinated ethylene propylene	8–2	0.76	30	Glass braid								
					14–8	0.36	14									
					6–2	0.36	14		Glass or other suitable braid material							
Mineral insulation (metal sheathed)	MI	90°C 194°F	Dry and wet locations	Magnesium oxide	18–16 ^c	0.58	23	Copper or alloy steel								
		250°C 482°F	For special applications ^b	16–10	0.91	36										
				9–4	1.27	50										
				3–500	1.40	55										
Moisture-, heat-, and oil-resistant thermoplastic	MTW	60°C 140°F	Machine tool wiring in wet locations	Flame-retardant, moisture-, heat-, and oil-resistant thermoplastic	22–12	(A)	(B)	(A)	(B)	(A) None (B) Nylon jacket or equivalent						
		90°C 194°F	Machine tool wiring in dry locations FPN: See NFPA 79.			0.76	0.38	30	15							
						0.76	0.51	30	20							
						1.14	0.76	45	30							
						1.52	0.76	60	30							
						1.52	1.02	60	40							
						2.03	1.27	80	50							
						2.41	1.52	95	60							
						2.79	1.78	110	70							
						Paper		85°C 185°F	For underground service conductors, or by special permission		Paper					Lead sheath
						Perfluoro alkoxy	PFA	90°C 194°F	Dry and damp locations		Perfluoro alkoxy	14–10	0.51	20	None	
								200°C 392°F	Dry locations—special applications ^b		8–2	0.76	30			
1–4/0	1.14	45														
Perfluoro alkoxy	PFAH	250°C 482°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus (nickel or nickel-coated copper only)	Perfluoro alkoxy	14–10					0.51	20	None				
				8–2	0.76	30										
				1–4/0	1.14	45										
				Thermoset	RHH	90°C 194°F	Dry and damp locations		14–10	1.14	45		Moisture-resistant, flame-retardant, nonmetallic covering ^a			
8–2	1.52	60														
1–4/0	2.03	80														
213–500	2.41	95														
501–1000	2.79	110														
1001–2000	3.18	125														
For 601–2000 see Table 310.62.																
Moisture-resistant thermoset	RHW ^d	75°C 167°F	Dry and wet locations						Flame-retardant, moisture-resistant thermoset	14–10	1.14	45		Moisture-resistant, flame-retardant, nonmetallic covering ^e		
										8–2	1.52	60				
										1–4/0	2.03	80				
				213–500	2.41	95										
				501–1000	2.79	110										
				1001–2000	3.18	125										
				For 601–2000 see Table 310.62.												

(Continued)

TABLE 19-1 Conductor Application and Insulations (*Continued*)

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of insulation			
					AWG or kcmil	mm	mils	Outer Covering ^a
Moisture-resistant thermoset	RHW-2	90°C 194°F	Dry and wet locations	Flame-retardant, moisture-resistant thermoset	14–10 8–2 1–4/0 213–500 501–1000 1001–2000 For 601–2000, see Table 310.62.	1.14 1.52 2.03 2.41 2.79 3.18	45 60 80 95 110 125	Moisture-resistant, flame-retardant, nonmetallic covering ^e
Silicone	SA	90°C 194°F 200°C 392°F	Dry and damp locations For special application ^b	Silicone rubber	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	1.14 1.52 2.03 2.41 2.79 3.18	45 60 80 95 110 125	Glass or other suitable braid material
Thermoset	SJS	90°C 194°F	Switchboard wiring only	Flame-retardant thermoset	14–10 8–2 1–4/0	0.76 1.14 2.41	30 45 95	None
Thermoplastic and fibrous outer braid	TBS	90°C 194°F	Switchboard wiring only	Thermoplastic	14–10 8 6–2 1–4/0	0.76 1.14 1.52 2.03	30 45 60 80	Flame-retardant, nonmetallic covering
Extended polytetrafluoro-ethylene	TFE	250°C 482°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus, or as open wiring (nickel or nickel-coated copper only)	Extruded polytetrafluoro-ethylene	14–10 8–2 1–4/0	0.51 0.76 1.14	20 30 45	None
Heat-resistant thermoplastic	THHN	90°C 194°F	Dry and damp locations	Flame-retardant, heat-resistant thermoplastic	14–12 10 8–6 4–2 1–4/0 250–500 501–1000	0.38 0.51 0.76 1.02 1.27 1.52 1.78	15 20 30 40 50 60 70	Nylon jacket or equivalent
Moisture- and heat-resistant thermoplastic	THHW	75°C 167°F 90°C 194°F	Wet location Dry location	Flame-retardant, moisture- and heat-resistant thermoplastic	14–10 8 6–2 1–4/0 213–500 501–1000	0.76 1.14 1.52 2.03 2.41 2.79	30 45 60 80 95 110	None
Moisture- and heat-resistant thermoplastic	THW ^d	75°C 167°F 90°C 194°F	Dry and wet locations Special applications within electric discharge lighting equipment. Limited to 1000 open-circuit volts or less (size 14-8 only as permitted in 410.33)	Flame-retardant, moisture- and heat-resistant thermoplastic	14–10 8 6–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.52 2.03 2.41 2.79 3.18	30 45 60 80 95 110 125	None

TABLE 19-1 Conductor Application and Insulations (*Continued*)

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of insulation			
					AWG or kcmil	mm	mils	Outer Covering ^a
Moisture- and heat-resistant thermoplastic	THWN ^d	75°C 167°F	Dry and wet location	Flame-retardant, moisture- and heat-resistant thermoplastic	14–12	0.38	15	Nylon jacket or equivalent
					10	0.51	20	
					8–6	0.76	30	
					4–2	1.02	40	
					1–4/0	1.27	50	
					250–500	1.52	60	
Moisture-resistant thermoplastic	TW	60°C 140°F	Dry and wet locations	Flame-retardant, moisture-resistant thermoplastic	501–1000	1.78	70	None
					14–10	0.76	30	
					8	1.14	45	
					6–2	1.52	60	
					1–4/0	2.03	80	
					213–500	2.41	95	
Underground feeder and branch-circuit cable—single conductor (for Type UF cable employing more than one conductor, see Article 340)	UF	60°C 140°F 75°C 167°F ⁷	See Article 340	Moisture-resistant Moisture- and heat-resistant	501–1000	2.79	110	Integral with insulation
					1001–2000	3.18	125	
					14–10	1.52	60 ^f	
					8–2	2.03	80 ^f	
					1–4/0	2.41	95 ^f	
Underground service-entrance cable—single conductor (for Type USE cable employing more than one conductor, see Article 338)	USE ^d	75°C 167°F	See Article 338	Heat- and moisture-resistant	14–10	1.14	5	Moisture-resistant nonmetallic covering (See 338.2.)
					8–2	1.52	60	
					1–4/0	2.03	80	
					213–500	2.41	95 ^h	
					501–1000	2.79	110	
					1001–2000	3.18	125	
Thermoset	XHH	90°C 194°F	Dry and damp location	Flame-retardant thermoset	14–10	0.76	30	None
					8–2	1.14	45	
					1–4/0	1.40	55	
					213–500	1.65	65	
					501–1000	2.03	80	
					1001–2000	2.41	95	
Moisture-resistant thermoset	XHHW ^d	90°C 194°F 167°F	Dry and damp location Wet location	Flame-retardant, moisture-resistant thermoset	14–10	0.76	30	None
					8–2	1.14	45	
					1–4/0	1.40	55	
					213–500	1.65	65	
					501–1000	2.03	80	
					1001–2000	2.41	95	
Moisture-resistant thermoset	XHHW-2	90°C 194°F	Dry and wet locations	Flame-retardant, moisture-resistant thermoset	14–10	0.76	30	None
					8–2	1.14	45	
					1–4/0	1.40	55	
					213–500	1.65	65	
					501–1000	2.03	80	
					1001–2000	2.41	95	
Modified ethylene tetrafluoro-ethylene	Z	90°C 194°F 150°C 302°F	Dry and damp locations Dry locations—special applications ^b	Modified ethylene tetrafluoro-ethylene	14–12	0.38	15	None
					10	0.51	20	
					8–4	0.64	25	
					3–1	0.89	35	
					1/0–4/0	1.14	45	

(Continued)

TABLE 19-1 Conductor Application and Insulations (*Continued*)

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of insulation			
					AWG or kcmil	mm	mils	Outer Covering ^d
Modified ethylene tetrafluoro-ethylene	ZW ^d	75°C	Wet locations	Modified ethylene tetrafluoro-ethylene	14–10	0.76	30	None
		167°F			8–2	1.14	45	
		90°C	Dry and damp locations					
		194°F						
		150°C	Dry locations—special applications ^b					
		302°F						

^aSome insulations do not require an outer covering.

^bWhere design conditions require maximum conductor operating temperatures above 90°C (194°F).

^cFor signaling circuits permitting 300-V insulation.

^dListed wire types designated with the suffix “2,” such as RHW-2, shall be permitted to be used at a continuous 90°C (194°F) operating temperature, wet or dry.

^eSome rubber insulations do not require an outer covering.

^fIncludes integral jacket.

^gFor ampacity limitation, see 340.80.

^hInsulation thickness shall be permitted to be 2.03 mm (80 mils) for listed Type USE conductors that have been subjected to special investigations. The nonmetallic covering over individual rubber-covered conductors of aluminum-sheathed cable and of lead-sheathed or multiconductor cable shall not be required to be flame retardant. For Type MC cable, see 330.104. For nonmetallic-sheathed cable, see Article 334, Part III. For Type UF cable, see Article 340, Part III.

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Cable-Assembly Systems. These are used extensively for concealed wiring not embedded in masonry or concrete. They may also be installed exposed in dry locations, and depending on the particular construction and ratings, in wet locations. Branch-circuit sizes are conventionally 600 V-rated. Cables rated for 5 through 15 kV are frequently used for primary distribution feeders in large commercial and industrial electrical systems.

In industrial plants and commercial utility areas, cable assemblies are often installed in expanded metal trays, ladder racks, or other approved cable-support systems.

Nonmetallic-sheathed cables are almost universally used in single family house wiring in the United States and in many multifamily occupancies. Armored cable is extensively used in commercial applications (see Fig. 19-2). Armored cable is used in extending branch circuits from outlet boxes on rigid conduit or EMT systems to lighting fixtures in suspended ceiling work.

Metal-clad type MC cable applies to constructions using interlocked armor, close fittings, or flexible corrugated tube over No. 18 copper, No. 12 aluminum, or larger conductors.

Two other metal-sheathed cables of special construction are recognized by the Code. Mineral-insulated metal-sheathed cable is sheathed with a continuous copper or steel outer covering, containing one or more conductors and insulated with highly compressed refractory mineral insulation. It is widely used in industrial power, control wiring and in either wet or dry locations.

MI must be terminated and connected by means of fittings designed and approved for the purpose.

Open wiring on knobs and cleats is rarely encountered in current work. Open feeders are still used in some industrial construction where low cost is a consideration, no safety hazard is involved, and appearance is unimportant (see Fig. 19-3).

Several cable assemblies have been developed for limited or particular uses, rather than for complete wiring systems for a building. The NEC should be consulted for specific requirements in each case.

Service-entrance (SE) cable is a form of armored or nonmetallic-sheathed cable specifically approved for service-entrance use. It is available in two types: SE, with a flame-retardant, moisture-resistant outer covering, and underground service-entrance cable suitable for direct burial in the ground.

TABLE 19-2A Allowable Ampacities of Single-Insulated Conductors, Rated 0 through 2000 V, 150°C through 250°C (302°F through 482°F), in Free Air, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 19-1)				Size AWG or kcmil
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PEA, SA	Types PFAH, TFE	Type Z	
Size AWG or kcmil	Copper		Nickel, or Nickel-coated Copper	Aluminum or Copper-clad Aluminum	Size AWG or kcmil
14	46	54	59	—	14
12	60	68	78	47	12
10	80	90	107	63	10
8	106	124	142	83	8
6	155	165	205	112	6
4	190	220	278	148	4
3	214	252	327	170	3
2	255	393	381	198	2
1	293	344	440	228	1
1/0	339	399	532	263	1/0
2/0	390	467	591	305	2/0
3/0	451	546	708	351	3/0
4/0	529	629	830	411	4/0

Correction Factors

Ambient Temperature (°C)	For ambient temperatures other than 40°C (104°F), multiply the allowable ampacities shown above by the appropriate factor shown below				Ambient Temperature (°F)
41–50	0.95	0.97	0.98	0.95	105–122
51–60	0.90	0.94	0.95	0.90	123–140
61–70	0.85	0.90	0.93	0.85	141–158
71–80	0.80	0.87	0.90	0.80	159–176
81–90	0.74	0.83	0.87	0.74	177–194
91–100	0.67	0.79	0.85	0.67	195–212
101–120	0.52	0.71	0.79	0.52	213–248
121–140	0.30	0.61	0.72	0.30	249–284
141–160	—	0.50	0.65	—	285–320
161–180	—	0.35	0.58	—	321–356
181–200	—	—	0.49	—	357–392
201–225	—	—	0.35	—	393–437

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TABLE 19-2B Allowable Ampacities of Insulated Conductors Rated 0 through 2000 Volts, 60°C through 90°C (140°F through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

	Temperature Rating of Conductor (See Table 19-1)						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
	Copper			Aluminum or Copper-clad Aluminum			
18	—	—	14	—	—	—	—
16*	—	—	18	—	—	—	—
14*	20	20	25	—	—	—	—
12*	25	25	30	20	20	25	12*
10	30	35	40	25	30	35	10*
8	40	50	55	30	40	45	8
6	55	65	75	40	50	60	6
4	70	85	95	55	65	75	4
3	85	100	110	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	150	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	190	230	255	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	355	420	475	285	340	385	600
700	385	460	520	310	375	420	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	450	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	520	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	560	665	750	470	560	630	2000

TABLE 19-2B Allowable Ampacities of Insulated Conductors Rated 0 through 2000 Volts, 60°C through 90°C (140°F through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F) (*Continued*)

Correction Factors							
Ambient Temperature (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below						Ambient Temperature (°F)
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

*Unless specifically permitted, the overcurrent protection shall not exceed 15 A for 14 AWG, 20 A for 12 AWG, and 30 A for 10 AWG copper; or 15 A for 12 AWG and 25 A for 10 AWG aluminum and copper-clad aluminum after any correction factors for ambient temperature and number of conductors have been applied.

Extensions, Raceways, Conduits, Wireways, and Busways. *Nonmetallic surface extensions* are 2-wire assemblies limited to exposed work in office (or residence) occupancies, where additional outlets are to be installed in the same room with the outlet from which the extension originates. The location must be dry and not subject to corrosive vapors. The voltage should not exceed 150 V between conductors.

Underplaster extensions have been used as a concealed-wiring method to install additional outlets on an existing branch circuit. They were eliminated from the NEC in 1993 as a specific article since other articles addressed this method.

In general, the raceway systems were developed for special purposes and are of more commercial importance and find a more varied use than the special cable-assembly systems discussed earlier. This is particularly true of underfloor and cellular raceways for concealed work and of wireways and busways for exposed work. In cases where great flexibility in the use of electric power is of importance, the application of one of these special systems should be considered. In each case, the NEC should be consulted for specific installation rules.

Flexible-metal conduit, consisting of a flexible metallic tube roughly similar to the armor of armored cable, is used generally with rigid-conduit or electrical metallic tubing systems, to provide flexible connections at motor terminals, for instance, or in place of the rigid product where installations of the latter would be difficult owing to numerous bends, close working quarters, etc. The conductors are installed after the flexible conduit is in place.

Surface metal raceways (see Fig. 19-4) are flat, rectangular wireways used for exposed work in dry locations. They are frequently used to install additional outlets in a building already wired, where concealment of conductors is difficult, and are also used for special purposes, for example, installation of cove lighting and for show-window reflectors. Unless made of a metal at least 0.040 in thick, they are limited to use on circuits not exceeding 300 V.

Liquidtight flexible-metal conduit is, as the name suggests, a type of flexible-metal conduit having an outer jacket impervious to liquids and terminated in liquidtight fitting. It is most widely used for connecting motors to rigid-conduit systems or fixed-equipment enclosures.

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TABLE 19-2C Allowable Ampacities of Single-Insulated Conductors Rated 0 through 2000 V in Free Air, Based on Ambient Air Temperature of 30°C (86°F)

	Temperature Rating of Conductor (See Table 19-1)						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
	18	—	—	18	—	—	—
16	—	—	24	—	—	—	—
14*	25	30	35	—	—	—	—
12*	30	35	40	25	30	35	12*
10*	40	50	55	35	40	40	10*
8	60	70	80	45	55	60	8
6	80	95	105	60	75	80	6
4	105	125	140	80	100	110	4
3	120	145	165	95	115	130	3
2	140	170	190	110	135	150	2
1	165	195	220	130	155	175	1
1/0	195	230	260	150	180	205	1/0
2/0	225	265	300	175	210	235	2/0
3/0	260	310	350	200	240	275	3/0
4/0	300	360	405	235	280	315	4/0
250	340	405	455	265	315	355	250
300	375	445	505	290	350	395	300
350	420	505	570	330	395	445	350
400	455	545	615	355	425	480	400
500	515	620	700	405	485	545	500
600	575	690	780	455	540	615	600
700	630	755	855	500	595	675	700
750	655	785	885	515	620	700	750
800	680	815	920	535	645	725	800
900	730	870	985	580	700	785	900
1000	780	935	1055	625	750	845	1000
1250	890	1065	1200	710	855	960	1250
1500	980	1175	1325	795	950	1075	1500
1750	1070	1280	1445	875	1050	1185	1750
2000	1155	1385	1560	960	1150	1335	2000

TABLE 19-2C Allowable Ampacities of Single-Insulated Conductors Rated 0 through 2000 V in Free Air, Based on Ambient Air Temperature of 30°C (86°F) (Continued)

Correction Factors							
Ambient Temperature (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below						Ambient Temperature (°F)
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

*Unless specifically permitted, the overcurrent protection shall not exceed 15 A for 14 AWG, 20 A for 12 AWG, and 30 A for 10 AWG copper; or 15 A for 12 AWG and 25 A for 10 AWG aluminum and copper-clad aluminum after any correction factors for ambient temperature and number of conductors have been applied.

Underfloor raceways (Fig. 19-5) are employed in buildings of fire-resistant construction to provide readily accessible raceways in the floor slab for light and power, telephone, and signal circuits. One, two, or three ducts are installed, depending on the desired uses. Junction boxes which mark each end of a run of raceway, and the tops of which are flush with the floor covering, make it possible to locate accurately the run of duct and, hence, to install additional outlets with the special tools provided by the manufacturer. Owing to its flexibility, this type of construction is particularly suitable for large office areas or where outlet locations are subject to change.

The *cellular-metal-floor raceway* involves a cellular-steel floor (Fig. 19-6a), which is a structural load-carrying element whose hollow cells form the wire raceway and a system of transverse headers, together with the necessary fittings and adapters. The headers are also wire raceways, providing electrical access from distribution points to any predetermined number of cells. The system can be designed to provide overall floor and ceiling electrical service for conductors not larger than No. 0 AWG, not only for light and power but also for telephone and signal circuits. The large internal-cell areas (normally on 6-in centers) afford adequate conductor space, while the complete floor and ceiling coverage provides for great flexibility in use during the building life, since access to headers and cells can be obtained at any time for additional outlets, new or rerouted circuits, etc.

Cellular-concrete-floor raceways are precast slabs with tubular “cells” designed to lineup in a continuous raceway. Cells terminate in metallic header ducts and other special fittings for connection to other parts of the electrical systems. Fittings approved for the purpose are inserted into the cell to provide for outlets (see Fig. 19-6b).

Structural raceways are formed-steel members which may be assembled to provide for the installation of electrical wires and cables. Such assemblies also provide for the installation of wiring devices in vertical members which may be concealed.

Wireways provide a convenient, exposed rectangular metal raceway or trough for no more than 30 current-carrying conductors or total conductor cross-sectional area not exceeding 20% of the interior cross-sectional area of the wireway. The product is available in several standard lengths, which are bolted together for continuous runs. Access at any point is through hinged covers and conduit knockouts. A complete array of fittings assures flexibility for various installation conditions.

Owing to their size, wireways can be used to advantage for large numbers of conductors, for a group of circuits leaving a branch-circuit panelboard or feeder distribution board.

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TABLE 19-2D Allowable Ampacities of Insulated Conductors Rated 0 through 2000 V, 150°C through 250°C (302°F through 482°F). Not More Than Three Current-Carrying Conductors in Raceway or Cable, Based on Ambient Air Temperature of 40°C (104°F)

	Temperature Rating of Conductor (See Table 19-1)				
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA, SA	Types PFAH, TFE	Type Z	
Size AWG or kcmil	Copper		Nickel, or Nickel-coated Copper	Aluminum or Copper-clad Aluminum	Size AWG or kcmil
14	34	36	39	—	14
12	43	45	54	30	12
10	55	60	73	44	10
8	76	83	93	57	8
6	96	110	117	75	6
4	120	125	148	94	4
3	143	152	166	109	3
2	160	171	191	124	2
1	186	197	215	145	1
1/0	215	229	244	169	1/0
2/0	251	260	273	198	2/0
3/0	288	297	308	227	3/0
4/0	332	346	361	260	4/0

Correction Factors					
Ambient Temperature (°C)	For ambient temperatures other than 40°C (104°F), multiply the allowable ampacities shown above by the appropriate factor shown below				Ambient Temperature (°F)
41–50	0.95	0.97	0.98	0.95	105–122
51–60	0.90	0.94	0.95	0.90	123–140
61–70	0.85	0.90	0.93	0.85	141–158
71–80	0.80	0.87	0.90	0.80	159–176
81–90	0.74	0.83	0.87	0.74	177–194
91–100	0.67	0.79	0.85	0.67	195–212
101–120	0.52	0.71	0.79	0.52	213–248
121–140	0.30	0.61	0.72	0.30	249–284
141–160	—	0.50	0.65	—	285–320
161–180	—	0.35	0.58	—	321–356
181–200	—	—	0.49	—	357–392
201–225	—	—	0.35	—	393–437

TABLE 19-2E Ampacities of Not More Than Three Single Insulated Conductors, Rated 0 through 2000 V, Supported on a Messenger, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 19-1)				Size AWG or kcmil
	75°C (167°F)	90°C (194°F)	75°C (167°F)	90°C (194°F)	
	Types RHW, THHW, THW, THWN, XHHW, ZW	Types MI, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHHW, XHHW-2, ZW-2	Types RHW, THW, THWN, XHHW	Types THHN, THHW, RHH, XHHW, RHW-2, XHHW-2, THW-2, THWN-2, USE-2, ZW-2	
	Copper		Aluminum or Copper-clad Aluminum		
8	57	66	44	51	8
6	76	89	59	69	6
4	101	117	78	91	4
3	118	138	92	107	3
2	135	158	106	123	2
1	158	185	123	144	1
1/0	183	214	143	167	1/0
2/0	212	247	165	193	2/0
3/0	245	287	192	224	3/0
4/0	287	335	224	262	4/0
250	320	374	251	292	250
300	359	419	282	328	300
350	397	464	312	364	350
400	430	503	339	395	400
500	496	580	392	458	500
600	553	647	440	514	600
700	610	714	488	570	700
750	638	747	512	598	750
800	660	773	532	622	800
900	704	826	572	669	900
1000	748	879	612	716	1000

Correction Factors					
Ambient Temperature (°C)	For ambient temperatures other than 40°C (104°F), multiply the allowable ampacities shown above by the appropriate factor shown below				Ambient Temperature (°F)
21–25	1.20	1.14	1.20	1.14	70–77
26–30	1.13	1.10	1.13	1.10	79–86
31–35	1.07	1.05	1.07	1.05	88–95
36–40	1.00	1.00	1.00	1.00	97–104
41–45	0.93	0.95	0.93	0.95	106–113
46–50	0.85	0.89	0.85	0.89	115–122
51–55	0.76	0.84	0.76	0.84	124–131
56–60	0.65	0.77	0.65	0.77	133–140
61–70	0.38	0.63	0.38	0.63	142–158
71–80	—	0.45	—	0.45	160–176

TABLE 19-2F Ampacities of Bare or Covered Conductors in Free Air, Based on 40°C (104°F) Ambient, 80°C (176°F). Total Conductor Temperature, 610 mm/sec (2 ft/sec) Wind Velocity

Copper Conductors				AAC Aluminum Conductors			
Bare		Covered		Bare		Covered	
AWG or kcmil	Amperes	AWG or kcmil	Amperes	AWG or kcmil	Amperes	AWG or kcmil	Amperes
8	98	8	103	8	76	8	80
6	124	6	130	6	96	6	101
4	155	4	163	4	121	4	127
2	209	2	219	2	163	2	171
1/0	282	1/0	297	1/0	220	1/0	231
2/0	329	2/0	344	2/0	255	2/0	268
3/0	382	3/0	401	3/0	297	3/0	312
4/0	444	4/0	466	4/0	346	4/0	364
250	494	250	519	266.8	403	266.8	423
300	556	300	584	336.4	468	336.4	492
500	773	500	812	397.5	522	397.5	548
750	1000	750	1050	477.0	588	477.0	617
1000	1193	1000	1253	556.5	650	556.5	682
—	—	—	—	636.0	709	636.0	744
—	—	—	—	795.0	819	795.0	860
—	—	—	—	954.0	920	—	—
—	—	—	—	1033.5	968	1033.5	1017
—	—	—	—	1272	1103	1272	1201
—	—	—	—	1590	1267	1590	1381
—	—	—	—	2000	1454	2000	1527

Busways (Fig. 19-7) are one of the more important recent developments for exposed heavy-capacity feeder and circuit wiring in industrial plants because of their flexibility in use, which makes them readily adaptable to future needs and to changing conditions such as relocation or revamping of production lines. The initial investment can be confined to immediate requirements and additions made at anytime as requirements increase. The system consists essentially of interconnected prefabricated lengths or sections of steel or aluminum duct which enclose bus bars mounted on insulators. Regularly spaced openings in the sides of the duct permit plugging in branch-circuit control devices of the circuit-breaker, fuse, or fused-switch type, for convenient control of individual or group motor drives, lighting or heating circuits, etc. The ease of relocating both the duct and control devices makes its use advantageous for supplying power to machines on assembly lines, mass production manufacturing, and other applications where flexibility of electric supply is essential. Busways are available in capacities ranging from about 125 to about 3000 A, for 3-phase 3- or 4-wire systems.

The so-called trolley duct (Fig. 19-8) is a variation of the busway in which the metal duct and electrical buses (either single-phase or 3-phase) are so arranged that access is had to the buses at any point in the run. Current is collected from the buses by movable trolleys to which are wired portable or movable electrical devices. In industrial plants, the system is used to supply power to cranes and hoists, to portable tools on assembly lines and benches, etc. It has found some application in drafting rooms, stock departments, and similar locations, where ability to move lighting units quickly is of advantage.

Multioutlet assemblies are surface-mounted raceways of metal or plastic with plug receptacle outlets at spaced intervals or provisions for the insertion of receptacles as desired. Multioutlet assemblies are widely used where a number of cord-connected appliances must be served (as along the back of a workbench or laboratory table). They are also used to provide greater convenience for the attachment of portable cords. In this application, they are usually installed along the top of the baseboard (as around the perimeter of a private office).

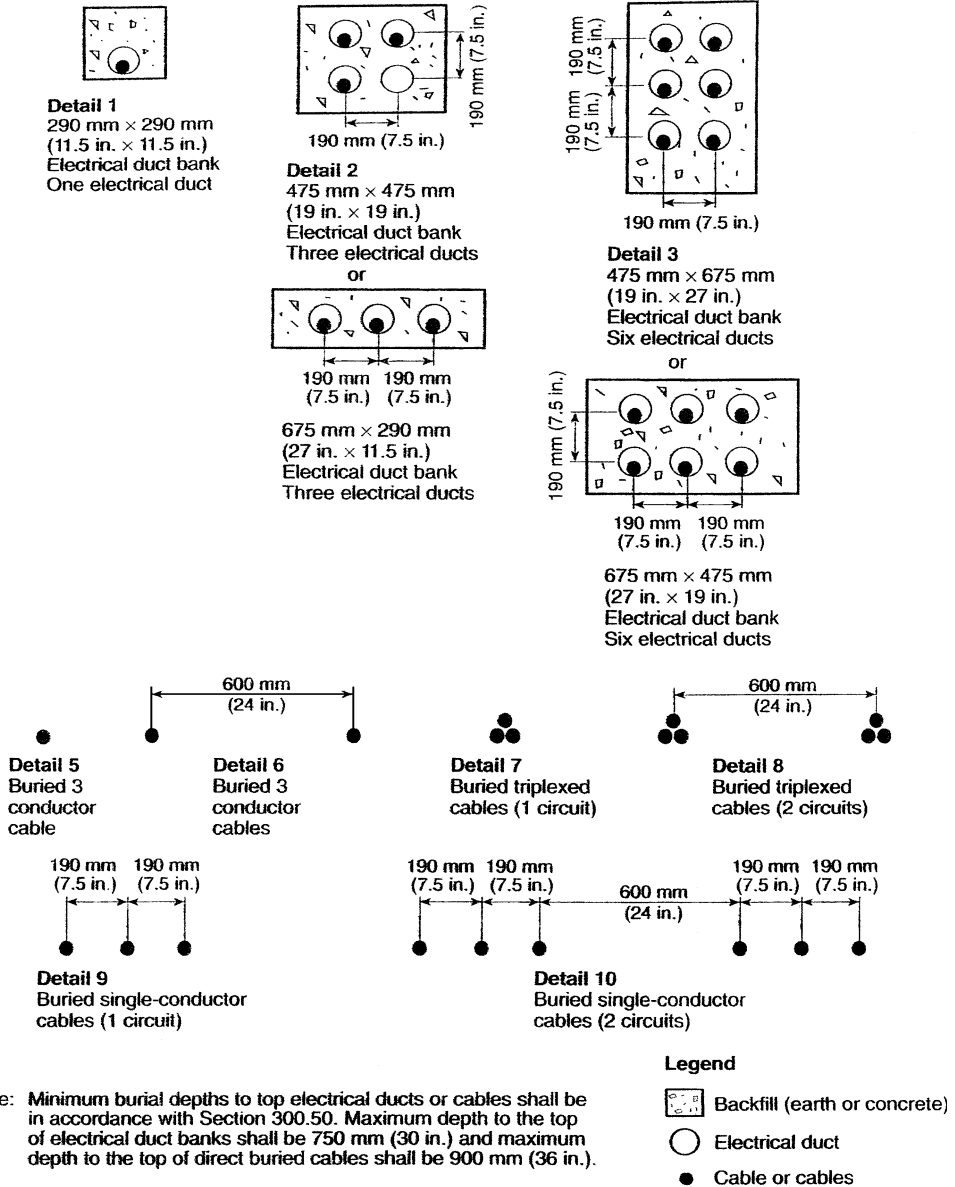


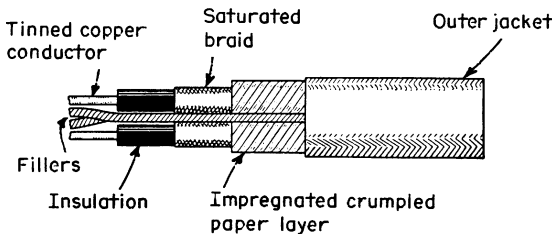
FIGURE 19-1 Configurations for buried systems using conductors in Tables 19-2A and 19-2C. (Reprinted with permission from NFPA 70-2005, *National Electrical Code*®, © 2004, National Fire Protection Association, Quincy, MA 02169. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.)

TABLE 19-3 Percent of Cross Section of Conduit and Tubing for Conductors

Number of Conductors	All Conductors Types
1	53
2	31
Over 2	40

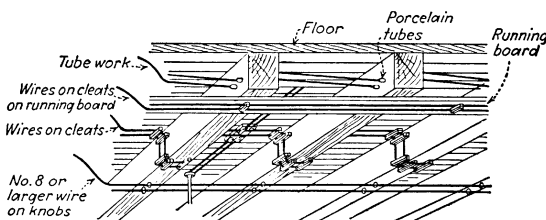
Based on common conditions of proper cabling and alignment of conductors where the length of the pull and the number of bends are within reasonable limits. It should be recognized that, for certain conditions, a larger size conduit or a lesser conduit fill should be considered.

When pulling three conductors or cables into a raceway, if the ratio of the raceway (inside diameter) to the conductor or cable (outside diameter) is between 2.8 and 3.2, jamming can occur. While jamming can occur when pulling four or more conductors or cables into a raceway, the probability is very low.

**FIGURE 19-2** Nonmetallic sheathed cable.

insulated conductors are based on an allowable temperature rise above an ambient of 30°C (86°F) and 40°C (104°F). A list of temperature ratings for types of insulated conductors is given in Table 19-1.

Allowable ampacities for copper conductors and aluminum conductors in accordance with the temperature rating of the insulation are given for installation in conduit and for installation in free air in Tables 19-2A through 19-2E (see also Table 19-4B).

**FIGURE 19-3** Methods of supporting open wiring.

Conductors for Building Wiring. The various types of conductor available for interior wiring, together with their sizes, insulations, and uses, are indicated in Tables 19-1 and 19-2. Rubber and thermoplastic insulations are available in a number of compounds and constructions for resistance to heat, moisture, or other environmental conditions.

Other insulations used in building wiring include magnesium oxide, fluorinated ethylene propylene, silicone rubber, and the long-familiar varnished-cambric and asbestos constructions, although asbestos is no longer used except under special conditions.

Various connector types are shown in Fig. 19-9.

Dimensions of *insulated conductors* and fixture wires are given in Table 19-4A.

Current-Carrying Capacity (Ampacity) and Other Properties. As the conductors of an electrical wiring system offer some resistance, a current-carrying conductor dissipates heat. Under practical conditions of installation and operation, the temperatures reached must not result in the destruction of the insulation or risk to surrounding material.

Tables of maximum allowable current-carrying capacity are given in the NEC. Allowable ampacities for insu-

To determine the permissible percent raceway fill for conductor combinations, see Table 19-3.*

Conductor and conduit diameters and areas are frequently necessary to calculate allowable fill. Nominal values for conductors are given in Table 19-4A and, for conduit and tubing, Tables 19-5A and 19-5B give resistance and reactance values of conductors in ohms per 304.8 m (1000 ft). Table 19-6 gives dimensions and area of conduit and tubing.

*Tables 19-3 through 19-7 are reprinted with permission from NFPA 70-2005, the *National Electrical Code*, © 2004, National Fire Protection Association, Quincy, Mass. 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject which is represented only by the standard in its entirety.

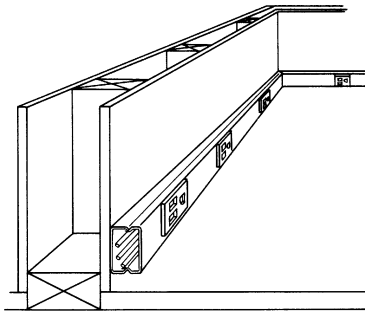


FIGURE 19-4 Typical surface raceway with plug receptacles.

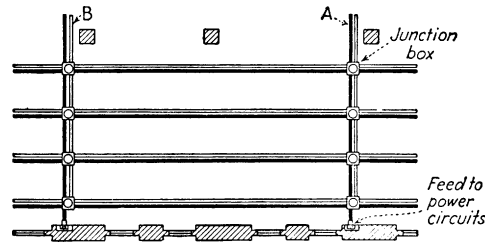


FIGURE 19-5 Layout of double underflow duct system: A—for power circuits; B—for signal and telephone circuits.

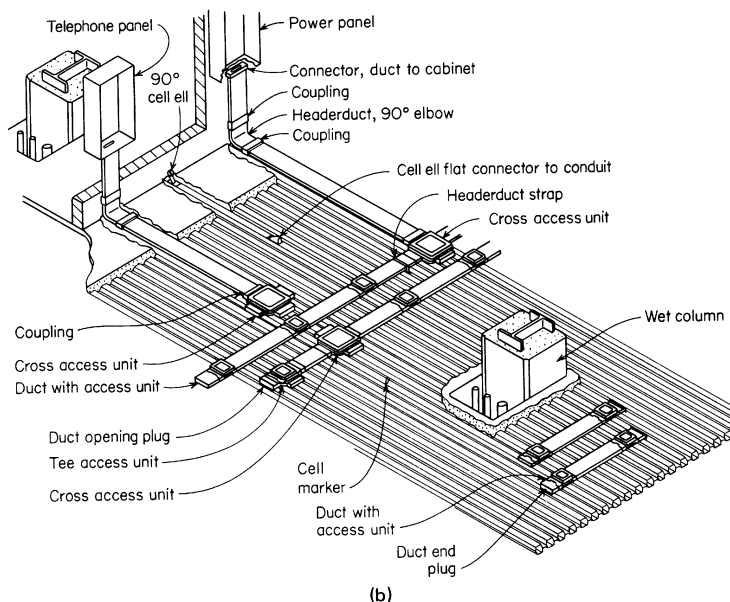
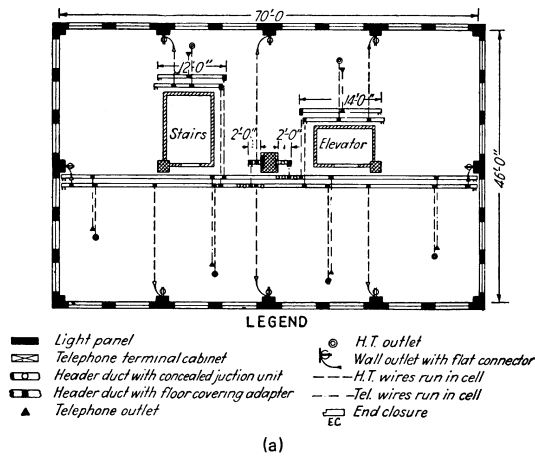


FIGURE 19-6 (a) Cellular-flow wiring layout; (b) floor ducts and access units.

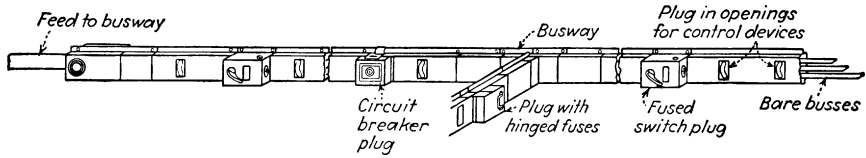


FIGURE 19-7 Units of busway distribution system.

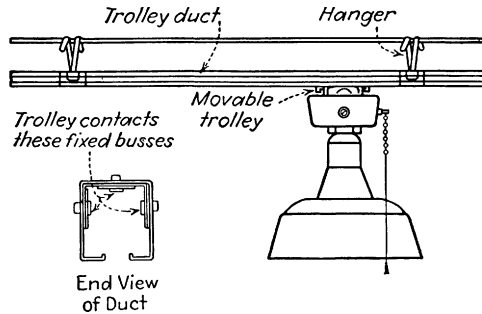


FIGURE 19-8 Trolley duct used for movable lighting fixture.

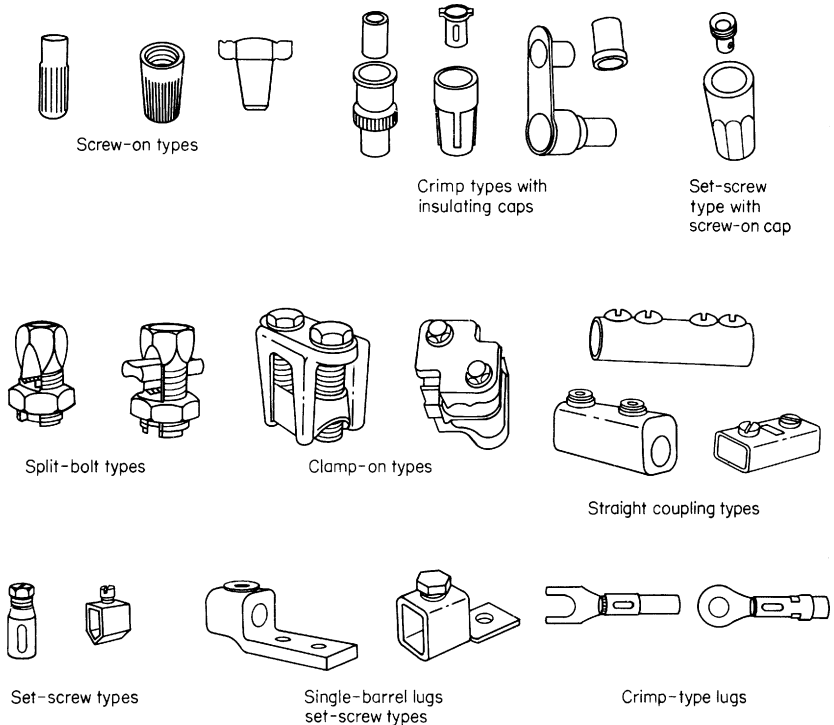


FIGURE 19-9 Types of wire connectors.

TABLE 19-4A Dimensions of Insulated Conductors and Fixture Wires

Type	Size (AWG or kcmil)	Approximate Diameter		Approximate Area		
		mm	in	mm ²	in ²	
Type: FFH-2, RFH-1, RFH-2, RHH*, RHW*, RHW-2*, RHH, RHW, RHW-2, SF-1, SF-2, SFF-1, SFF-2, TF, TFF, THHW, THW, THW-2, TW, XF, XFF						
RFH-2, FFH-2	18	3.454	0.136	9.355	0.0145	
	16	3.759	0.148	11.10	0.0172	
RHH, RHW, RHW-2	14	4.902	0.193	18.90	0.0293	
	12	5.385	0.212	22.77	0.0353	
	10	5.994	0.236	28.19	0.0437	
	8	8.280	0.326	53.87	0.0835	
	6	9.246	0.364	67.16	0.1041	
	4	10.46	0.412	86.00	0.1333	
	3	11.18	0.440	98.13	0.1521	
	2	11.99	0.472	112.9	0.1750	
	1	14.78	0.582	171.6	0.2660	
	1/0	15.80	0.622	196.1	0.3039	
	2/0	16.97	0.668	226.1	0.3505	
	3/0	18.29	0.720	262.7	0.4072	
	4/0	19.76	0.778	306.7	0.4754	
	250	22.73	0.895	405.9	0.6291	
	300	24.13	0.950	457.3	0.7088	
	350	25.43	1.001	507.7	0.7870	
	400	26.62	1.048	556.5	0.8626	
	500	28.78	1.133	650.5	1.0082	
	600	31.57	1.243	782.9	1.2135	
	700	33.38	1.314	874.9	1.3561	
	750	34.24	1.348	920.8	1.4272	
	800	35.05	1.380	965.0	1.4957	
	900	36.68	1.444	1057	1.6377	
	1000	38.15	1.502	1143	1.7719	
	1250	43.92	1.729	1515	2.3479	
	1500	47.04	1.852	1738	2.6938	
	1750	49.94	1.966	1959	3.0357	
	2000	52.63	2.072	2175	3.3719	
	SF-2, SFF-2	18	3.073	0.121	7.419	0.0115
		16	3.378	0.133	8.968	0.0139
14		3.759	0.148	11.10	0.0172	
SF-1, SFF-1	18	2.311	0.091	4.194	0.0065	
RFH-1, XF, XFF	18	2.692	0.106	5.161	0.0080	
TF, TFF, XF, XFF	16	2.997	0.118	7.032	0.0109	
TW, XF, XFF, THHW, THW, THW-2	14	3.378	0.133	8.968	0.0139	

(Continued)

TABLE 19-4A Dimensions of Insulated Conductors and Fixture Wires (*Continued*)

Type	Size (AWG or kcmil)	Approximate Diameter		Approximate Area	
		mm	in	mm ²	in ²
TW, THHW, THW, THW-2	12	3.861	0.152	11.68	0.0181
	10	4.470	0.176	15.68	0.0243
	8	5.994	0.236	28.19	0.0437
RHH*, RHW*, RHW-2*	14	4.140	0.163	13.48	0.0209
RHH*, RHW*, RHW-2*, XF, XFF	12	4.623	0.182	16.77	0.0260
Type: RHH*, RHW*, RHW-2*, THHN, THHW, THW, THW-2, TFN, TFFN, THWN, THWN-2, XF, XFF					
RHH*, RHW*, RHW-2*, XF, XFF	10	5.232	0.206	21.48	0.0333
RHH*, RHW*, RHW-2*	8	6.756	0.266	35.87	0.0556
TW, THW, THHW, THW-2, RHH*, RHW*, RHW-2*	6	7.722	0.304	46.84	0.0726
	4	8.941	0.352	62.77	0.0973
	3	9.652	0.380	73.16	0.1134
	2	10.46	0.412	86.00	0.1333
	1	12.50	0.492	122.6	0.1901
	1/0	13.51	0.532	143.4	0.2223
	2/0	14.68	0.578	169.3	0.2624
	3/0	16.00	0.630	201.1	0.3117
	4/0	17.48	0.688	239.9	0.3718
	250	19.43	0.765	296.5	0.4596
	300	20.83	0.820	340.7	0.5281
	350	22.12	0.871	384.4	0.5958
	400	23.32	0.918	427.0	0.6619
	500	25.48	1.003	509.7	0.7901
	600	28.27	1.113	627.7	0.9729
	700	30.07	1.184	710.3	1.1010
	750	30.94	1.218	751.7	1.1652
	800	31.75	1.250	791.7	1.2272
	900	33.38	1.314	874.9	1.3561
	1000	34.85	1.372	953.8	1.4784
	1250	39.09	1.539	1200	1.8602
	1500	42.21	1.662	1400	2.1695
	1750	45.11	1.776	1598	2.4773
	2000	47.80	1.882	1795	2.7818
TFN, TFFN	18	2.134	0.084	3.548	0.0055
	16	2.438	0.096	4.645	0.0072

TABLE 19-4A Dimensions of Insulated Conductors and Fixture Wires (*Continued*)

Type	Size (AWG or kcmil)	Approximate Diameter		Approximate Area	
		mm	in	mm ²	in ²
THHN, THWN, THWN-2	14	2.819	0.111	6.258	0.0097
	12	3.302	0.130	8.581	0.0133
	10	4.166	0.164	13.61	0.0211
	8	5.486	0.216	23.61	0.0366
	6	6.452	0.254	32.71	0.0507
	4	8.230	0.324	53.16	0.0824
	3	8.941	0.352	62.77	0.0973
	2	9.754	0.384	74.71	0.1158
	1	11.33	0.446	100.8	0.1562
	1/0	12.34	0.486	119.7	0.1855
	2/0	13.51	0.532	143.4	0.2223
	3/0	14.83	0.584	172.8	0.2679
	4/0	16.31	0.642	208.8	0.3237
	250	18.06	0.711	256.1	0.3970
	300	19.46	0.766	297.3	0.4608
Type: FEP, FEPB, PAF, PAFF, PF, PFA, PFAH, PFF, PGF, PGFF, PTF, PTFF, TFE, THHN, THWN, THWN-2, Z, ZF, ZFF					
THHN, THWN, THWN-2	350	20.75	0.817	338.2	0.5242
	400	21.95	0.864	378.3	0.5863
	500	24.10	0.949	456.3	0.7073
	600	26.70	1.051	559.7	0.8676
	700	28.50	1.122	637.9	0.9887
	750	29.36	1.156	677.2	1.0496
	800	30.18	1.188	715.2	1.1085
	900	31.80	1.252	794.3	1.2311
	1000	33.27	1.310	869.5	1.3478
PF, PGFF, PGF, PFF, PTF, PAF, PTFF, PAFF	18	2.184	0.086	3.742	0.0058
	16	2.489	0.098	4.839	0.0075
PF, PGFF, PGF, PFF, PTF, PAF, PTFF, PAFF, TFE, FEP, PFA, FEPB, PFAH	14	2.870	0.113	6.452	0.0100
TFE, FEP, PFA, FEPB, PFAH	12	3.353	0.132	8.839	0.0137
	10	3.962	0.156	12.32	0.0191
	8	5.232	0.206	21.48	0.0333
	6	6.198	0.244	30.19	0.0468
	4	7.417	0.292	43.23	0.0670
	3	8.128	0.320	51.87	0.0804
	2	8.941	0.352	62.77	0.0973
TFE, PFAH	1	10.72	0.422	90.26	0.1399
TFE, PFA, PFAH, Z	1/0	11.73	0.462	108.1	0.1676
	2/0	12.90	0.508	130.8	0.2027
	3/0	14.22	0.560	158.9	0.2463
	4/0	15.70	0.618	193.5	0.3000
ZF, ZFF	18	1.930	0.076	2.903	0.0045
	16	2.235	0.088	3.935	0.0061
Z, ZF, ZFF	14	2.616	0.103	5.355	0.0083

(Continued)

TABLE 19-4A Dimensions of Insulated Conductors and Fixture Wires (*Continued*)

Type	Size (AWG or kcmil)	Approximate Diameter		Approximate Area	
		mm	in	mm ²	in ²
Z	12	3.099	0.122	7.548	0.0117
	10	3.962	0.156	12.32	0.0191
	8	4.978	0.196	19.48	0.0302
	6	5.944	0.234	27.74	0.0430
	4	7.163	0.282	40.32	0.0625
	3	8.382	0.330	55.16	0.0855
	2	9.195	0.362	66.39	0.1029
	1	10.21	0.402	81.87	0.1269
Type: KF-1, KF-2, KFF-1, KFF-2, XHH, XHHW, XHHW-2, ZW					
XHHW, ZW, XHHW-2, XHH	14	3.378	0.133	8.968	0.0139
	12	3.861	0.152	11.68	0.0181
	10	4.470	0.176	15.68	0.0243
	8	5.994	0.236	28.19	0.0437
	6	6.960	0.274	38.06	0.0590
	4	8.179	0.322	52.52	0.0814
	3	8.890	0.350	62.06	0.0962
	2	9.703	0.382	73.94	0.1146
XHHW, XHHW-2, XHH	1	11.23	0.442	98.97	0.1534
	1/0	12.24	0.482	117.7	0.1825
	2/0	13.41	0.528	141.3	0.2190
	3/0	14.73	0.58	170.5	0.2642
	4/0	16.21	0.638	206.3	0.3197
	250	17.91	0.705	251.9	0.3904
	300	19.30	0.76	292.6	0.4536
	350	20.60	0.811	333.3	0.5166
	400	21.79	0.858	373.0	0.5782
	500	23.95	0.943	450.6	0.6984
	600	26.75	1.053	561.9	0.8709
	700	28.55	1.124	640.2	0.9923
	750	29.41	1.158	679.5	1.0532
	800	30.23	1.190	717.5	1.1122
	900	31.85	1.254	796.8	1.2351
	1000	33.32	1.312	872.2	1.3519
	1250	37.57	1.479	1108	1.7180
	1500	40.69	1.602	1300	2.0157
	1750	43.59	1.716	1492	2.3127
	2000	46.28	1.822	1682	2.6073
KF-2, KFF-2	18	1.600	0.063	2.000	0.0031
	16	1.905	0.075	2.839	0.0044
	14	2.286	0.090	4.129	0.0064
	12	2.769	0.109	6.000	0.0093
	10	3.378	0.133	8.968	0.0139
KF-1, KFF-1	18	1.448	0.057	1.677	0.0026
	16	1.753	0.069	2.387	0.0037
	14	2.134	0.084	3.548	0.0055
	12	2.616	0.103	5.355	0.0083
	10	3.226	0.127	8.194	0.0127

*Types RHH, RHW, and RHW-2 without outer covering

TABLE 19-4B Compact Aluminum Building Wire Nominal Dimensions* and Areas

Size (AWG or kcmil)	Bare Conductor		Types THW and THHW				Type THHN				Type XHHW				Size, (AWG or kcmil)
	Diameter		Approximate Diameter		Approximate Area		Approximate Diameter		Approximate Area		Approximate Diameter		Approximate Area		
	mm	in	mm	in	mm ²	in ²	mm	in	mm ²	in ²	mm	in	mm ²	in ²	
8	3.404	0.134	6.477	0.255	32.90	0.0510	—	—	—	—	5.690	0.224	25.42	0.0394	8
6	4.293	0.169	7.366	0.290	42.58	0.0660	6.096	0.240	29.16	0.0452	6.604	0.260	34.19	0.0530	6
4	5.410	0.213	8.509	0.335	56.84	0.0881	7.747	0.305	47.10	0.0730	7.747	0.305	47.10	0.0730	4
2	6.807	0.268	9.906	0.390	77.03	0.1194	9.144	0.360	65.61	0.1017	9.144	0.360	65.61	0.1017	2
1	7.595	0.299	11.81	0.465	109.5	0.1698	10.54	0.415	87.23	0.1352	10.54	0.415	87.23	0.1352	1
1/0	8.534	0.336	12.70	0.500	126.6	0.1963	11.43	0.450	102.6	0.1590	11.43	0.450	102.6	0.1590	1/0
2/0	9.550	0.376	13.84	0.545	150.5	0.2332	12.57	0.495	124.1	0.1924	12.45	0.490	121.6	0.1885	2/0
3/0	10.74	0.423	14.99	0.590	176.3	0.2733	13.72	0.540	147.7	0.2290	13.72	0.540	147.7	0.2290	3/0
4/0	12.07	0.475	16.38	0.645	210.8	0.3267	15.11	0.595	179.4	0.2780	14.99	0.590	176.3	0.2733	4/0
250	13.21	0.520	18.42	0.725	266.3	0.4128	17.02	0.670	227.4	0.3525	16.76	0.660	220.7	0.3421	250
300	14.48	0.570	19.69	0.775	304.3	0.4717	18.29	0.720	262.6	0.4071	18.16	0.715	259.0	0.4015	300
350	15.65	0.616	20.83	0.820	340.7	0.5281	19.56	0.770	300.4	0.4656	19.30	0.760	292.6	0.4536	350
400	16.74	0.659	21.97	0.865	379.1	0.5876	20.70	0.815	336.5	0.5216	20.32	0.800	324.3	0.5026	400
500	18.69	0.736	23.88	0.940	447.7	0.6939	22.48	0.885	396.8	0.6151	22.35	0.880	392.4	0.6082	500
600	20.65	0.813	26.67	1.050	558.6	0.8659	25.02	0.985	491.6	0.7620	24.89	0.980	486.6	0.7542	600
700	22.28	0.877	28.19	1.110	624.3	0.9676	26.67	1.050	558.6	0.8659	26.67	1.050	558.6	0.8659	700
750	23.06	0.908	29.21	1.150	670.1	1.0386	27.31	1.075	585.5	0.9076	27.69	1.090	602.0	0.9331	750
900	23.37	0.999	31.09	1.224	759.1	1.1766	30.33	1.194	722.5	1.1196	29.69	1.169	692.3	1.0733	900
1000	26.92	1.060	32.64	1.285	836.6	1.2968	31.88	1.255	798.1	1.2370	31.24	1.230	766.6	1.1882	1000

*Dimensions are from industry sources.

TABLE 19-5A Conductor Properties

Size (AWG or kcmil)	Conductors										Direct-Current Resistance at 75°C (167°F)							
	Stranding				Overall				Copper				Aluminum					
	Area		Diameter		Diameter		Area		Uncoated		Coated		Aluminum					
mm ²	Circular mils	Quantity	mm	in	mm	in	mm ²	in ²	ohm/ km	ohm/ kFT	ohm/ km	ohm/ kFT	ohm/ km	ohm/ kFT	ohm/ km	ohm/ kFT		
18	0.823	1620	—	—	1.02	0.040	0.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8				
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1			
16	1.31	2580	1	—	—	1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05			
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21			
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06			
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17			
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18			
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25			
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00			
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04			
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26			
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28			
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808			
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508			
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403			
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319			
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087	0.505	0.154	0.524	0.160	0.829	0.253			
1/0	53.49	105600	19	1.89	0.074	9.45	0.372	70.41	0.109	0.399	0.122	0.415	0.127	0.660	0.201			
2/0	67.43	133100	19	2.13	0.084	10.62	0.418	88.74	0.137	0.3170	0.0967	0.329	0.101	0.523	0.159			
3/0	85.01	167800	19	2.39	0.094	11.94	0.470	111.9	0.173	0.2512	0.0766	0.2610	0.0797	0.413	0.126			
4/0	107.2	211600	19	2.68	0.106	13.41	0.528	141.1	0.219	0.1996	0.0608	0.2050	0.0626	0.328	0.100			
250	127	—	37	2.09	0.082	14.61	0.575	168	0.260	0.1687	0.0515	0.1753	0.0535	0.2778	0.0847			
300	152	—	37	2.29	0.090	16.00	0.630	201	0.312	0.1409	0.0429	0.1463	0.0446	0.2318	0.0707			
350	177	—	37	2.47	0.097	17.30	0.681	235	0.364	0.1205	0.0367	0.1252	0.0382	0.1984	0.0605			
400	203	—	37	2.64	0.104	18.49	0.728	268	0.416	0.1053	0.0321	0.1084	0.0331	0.1737	0.0529			
500	253	—	37	2.95	0.116	20.65	0.813	336	0.519	0.0845	0.0258	0.0869	0.0265	0.1391	0.0424			
600	304	—	61	2.52	0.099	22.68	0.893	404	0.626	0.0704	0.0214	0.0732	0.0223	0.1159	0.0353			

700	355	—	61	2.72	0.107	24.49	0.964	471	0.730	0.0603	0.0184	0.0622	0.0189	0.0994	0.0303
750	380	—	61	2.82	0.111	25.35	0.998	505	0.782	0.0563	0.0171	0.0579	0.0176	0.0927	0.0282
800	405	—	61	2.91	0.114	26.16	1.030	538	0.834	0.0528	0.0161	0.0544	0.0166	0.0868	0.0265
900	456	—	61	3.09	0.122	27.79	1.094	606	0.940	0.0470	0.0143	0.0481	0.0147	0.0770	0.0235
1000	507	—	61	3.25	0.128	29.26	1.152	673	1.042	0.0423	0.0129	0.0434	0.0132	0.0695	0.0212
1250	633	—	91	2.98	0.117	32.74	1.289	842	1.305	0.0338	0.0103	0.0347	0.0106	0.0554	0.0169
1500	760	—	91	3.26	0.128	35.86	1.412	1011	1.566	0.02814	0.00858	0.02814	0.00883	0.0464	0.0141
1750	887	—	127	2.98	0.117	38.76	1.526	1180	1.829	0.02410	0.00735	0.02410	0.00756	0.0397	0.0121
2000	1013	—	127	3.19	0.126	41.45	1.632	1349	2.092	0.02109	0.00643	0.02109	0.00662	0.0348	0.0106

Notes:

1. These resistance values are valid only for the parameters as given. Using conductors having coated strands, different stranding type, and, especially, other temperatures changes the resistance.
2. Formula for temperature change: $R_2 = R_1 [1 + \alpha (T_2 - 75)]$ where $\alpha_{cu} = 0.00323$, $\alpha_{al} = 0.00330$ at 75°C .
3. Conductors with compact and compressed stranding have about 9% and 3% respectively, smaller bare conductor diameters than those shown. See Table 5A for actual compact cable dimensions.
4. The IACS conductivities used: bare copper = 100%, aluminum = 61%.
5. Class B stranding is listed as well as solid for some sizes. Its overall diameter and area is that of its circumscribing circle.

FPN: The construction information is per NEMA WC8-1992 or ANSI/UL 1581-1998. The resistance is calculated per National Bureau of Standards Handbook 100, dated 1966, and Handbook 109, dated 1972.

TABLE 19-5B Alternating-Current Resistance and Reactance for 600-V Cables, 3-Phase, 60 Hz, 75°C (167°F)—Three Single Conductors in Conduit

Size (AWG or kcmil)	Ohms to Neutral per Kilometer											
	Ohms to Neutral per 1000 Feet											
	X_L (Reactance) for All Wires			Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective Z at 0.85 PF for Uncoated Copper Wires		
	PVC, Aluminum Conducts	Steel Conduit		PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit
14	0.190 0.058	0.240 0.073	10.2 3.1	10.2 3.1	10.2 3.1	10.2 3.1	— —	— —	— —	8.9 2.7	8.9 2.7	8.9 2.7
12	0.177 0.054	0.223 0.068	6.6 2.0	6.6 2.0	10.5 3.2	10.5 3.2	10.5 3.2	5.6 1.7	5.6 1.7	9.2 2.8	9.2 2.8	9.2 2.8
10	0.164 0.050	0.207 0.063	3.9 1.2	3.9 1.2	6.6 2.0	6.6 2.0	6.6 2.0	3.6 1.1	3.6 1.1	5.9 1.8	5.9 1.8	5.9 1.8
8	0.171 0.052	0.213 0.065	2.56 0.78	2.56 0.78	4.3 1.3	4.3 1.3	4.3 1.3	2.26 0.69	2.26 0.69	3.6 1.1	3.6 1.1	3.6 1.1
6	0.167 0.051	0.210 0.064	1.61 0.49	1.61 0.49	2.66 0.81	2.66 0.81	2.66 0.81	1.44 0.44	1.48 0.45	2.33 0.71	2.36 0.72	2.36 0.72
4	0.157 0.048	0.197 0.060	1.02 0.31	1.02 0.31	1.67 0.51	1.67 0.51	1.67 0.51	0.95 0.29	0.95 0.29	1.51 0.46	1.51 0.46	1.51 0.46
3	0.154 0.047	0.194 0.059	0.82 0.25	0.82 0.25	1.35 0.41	1.31 0.40	1.31 0.40	0.75 0.23	0.79 0.24	1.21 0.37	1.21 0.37	1.21 0.37
2	0.148 0.045	0.187 0.057	0.66 0.20	0.66 0.20	1.05 0.32	1.05 0.32	1.05 0.32	0.62 0.19	0.66 0.20	0.98 0.30	0.98 0.30	0.98 0.30
1	0.151 0.046	0.187 0.057	0.52 0.16	0.52 0.16	0.85 0.26	0.82 0.25	0.82 0.25	0.52 0.16	0.52 0.16	0.79 0.24	0.79 0.24	0.82 0.25
1/0	0.144 0.044	0.180 0.055	0.43 0.13	0.43 0.13	0.69 0.21	0.66 0.20	0.66 0.20	0.43 0.13	0.43 0.13	0.62 0.19	0.66 0.20	0.66 0.20
2/0	0.141 0.043	0.177 0.054	0.33 0.10	0.33 0.10	0.52 0.16	0.52 0.16	0.52 0.16	0.36 0.11	0.36 0.11	0.52 0.16	0.52 0.16	0.52 0.16

3/0	0.138 0.042	0.171 0.052	0.253 0.077	0.269 0.082	0.259 0.079	0.43 0.13	0.43 0.13	0.43 0.13	0.308 0.094	0.43 0.13	0.43 0.13	0.46 0.14	3/0
4/0	0.135 0.041	0.167 0.051	0.203 0.062	0.220 0.067	0.207 0.063	0.33 0.10	0.36 0.11	0.33 0.10	0.262 0.080	0.36 0.11	0.36 0.11	0.36 0.11	4/0
250	0.135 0.041	0.171 0.052	0.171 0.052	0.187 0.057	0.177 0.054	0.279 0.085	0.295 0.090	0.282 0.086	0.240 0.073	0.308 0.094	0.322 0.098	0.33 0.10	250
300	0.135 0.041	0.167 0.051	0.144 0.044	0.161 0.049	0.148 0.045	0.233 0.071	0.249 0.076	0.236 0.072	0.213 0.065	0.269 0.082	0.282 0.086	0.289 0.088	300
350	0.131 0.040	0.164 0.050	0.125 0.038	0.141 0.043	0.128 0.039	0.200 0.061	0.217 0.066	0.207 0.063	0.190 0.058	0.240 0.073	0.253 0.077	0.262 0.080	350
400	0.131 0.040	0.161 0.049	0.108 0.033	0.125 0.038	0.115 0.035	0.177 0.054	0.194 0.059	0.180 0.055	0.174 0.053	0.217 0.066	0.233 0.071	0.240 0.073	400
500	0.128 0.039	0.157 0.048	0.089 0.027	0.105 0.032	0.095 0.029	0.141 0.043	0.157 0.048	0.148 0.045	0.157 0.048	0.187 0.057	0.200 0.061	0.210 0.064	500
600	0.128 0.039	0.157 0.048	0.075 0.023	0.092 0.028	0.082 0.025	0.118 0.036	0.135 0.041	0.125 0.038	0.144 0.044	0.167 0.051	0.180 0.055	0.190 0.058	600
750	0.125 0.038	0.157 0.048	0.062 0.019	0.079 0.024	0.069 0.021	0.095 0.029	0.112 0.034	0.102 0.031	0.141 0.043	0.148 0.045	0.161 0.049	0.171 0.052	750
1000	0.121 0.037	0.151 0.046	0.049 0.015	0.062 0.019	0.059 0.018	0.075 0.023	0.089 0.027	0.082 0.025	0.131 0.040	0.128 0.039	0.138 0.042	0.151 0.046	1000

Notes:

1. These values are based on the following constants: UL-Type RHH wires with Class B stranding, in cradled configuration. Wire conductivities are 100% IACS copper and 61% IACS aluminum, and aluminum conduit is 45% IACS. Capacitive reactance is ignored, since it is negligible at these voltages. These resistance values are valid only at 75°C (167°F) and for the parameters as given, but are representative for 600-V wire types operating at 60 Hz.

2. *Effective Z* is defined as $R \cos(\theta) + X \sin(\theta)$, where θ is the power factor angle of the circuit. Multiplying current by effective impedance gives a good approximation for line-to-neutral voltage drop. Effective impedance values shown in this table are valid only at 0.85 power factor. For another circuit power factor (PF), effective impedance (Z_e) can be calculated from R and X_L values given in this table as follows: $Z_e = R \times PF + X_L \sin[\arccos(PF)]$.

19-30 SECTION NINETEEN

TABLE 19-6 Dimensions and Percent Area of Conduit and Tubing (Areas of Conduit or Tubing for the Combinations of Wires Permitted in Table 1, Chapter 9)

Article 358—Electrical Metallic Tubing (EMT)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
16	1/2	15.8	0.622	196	0.304	118	0.182	104	0.161	61	0.094	78	0.122
21	3/4	20.9	0.824	343	0.533	206	0.320	182	0.283	106	0.165	137	0.213
27	1	26.6	1.049	556	0.864	333	0.519	295	0.458	172	0.268	222	0.346
35	1 1/4	35.1	1.380	968	1.496	581	0.897	513	0.793	300	0.464	387	0.598
41	1 1/2	40.9	1.610	1314	2.036	788	1.221	696	1.079	407	0.631	526	0.814
53	2	52.5	2.067	2165	3.356	1299	2.013	1147	1.778	671	1.040	866	1.342
63	2 1/2	69.4	2.731	3783	5.858	2270	3.515	2005	3.105	1173	1.816	1513	2.343
78	3	85.2	3.356	5701	8.846	3421	5.307	3022	4.688	1767	2.742	2280	3.538
91	3 1/2	97.4	3.834	7451	11.545	4471	6.927	3949	6.119	2310	3.579	2980	4.618
103	4	110.1	4.334	9521	14.753	5712	8.852	5046	7.819	2951	4.573	3808	5.901
Article 362—Electrical Nonmetallic Tubing (ENT)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
16	1/2	14.2	0.560	158	0.246	95	0.148	84	1.131	49	0.076	63	0.099
21	3/4	19.3	0.760	293	0.454	176	0.272	155	0.240	91	0.141	117	0.181
27	1	25.4	1.000	507	0.785	304	0.471	269	0.416	157	0.243	203	0.314
35	1 1/4	34.0	1.340	908	1.410	545	0.846	481	0.747	281	0.437	363	0.564
41	1 1/2	39.9	1.570	1250	1.936	750	1.162	663	1.026	388	0.600	500	0.774
53	2	51.3	2.020	2067	3.205	1240	1.923	1095	1.699	641	0.993	827	1.282
63	2 1/2	—	—	—	—	—	—	—	—	—	—	—	—
78	3	—	—	—	—	—	—	—	—	—	—	—	—
91	3 1/4	—	—	—	—	—	—	—	—	—	—	—	—
Article 348—Flexible Metal Conduit (FMC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	3/8	9.7	0.384	74	0.116	44	0.069	39	0.061	23	0.036	30	0.046
16	1/2	16.1	0.635	204	0.317	122	0.190	108	0.168	63	0.098	81	0.127
21	3/4	20.9	0.824	343	0.533	206	0.320	182	0.283	106	0.165	137	0.213
27	1	25.9	1.020	527	0.817	316	0.490	279	0.433	163	0.253	211	0.327
35	1 1/4	32.4	1.275	824	1.277	495	0.766	437	0.677	256	0.396	330	0.511
41	1 1/2	39.1	1.538	1201	1.858	720	1.115	636	0.985	372	0.576	480	0.743
53	2	51.8	2.040	2107	3.269	1264	1.961	1117	1.732	653	1.013	843	1.307
63	2 1/2	63.5	2.500	3167	4.909	1900	2.945	1678	2.602	982	1.522	1267	1.963
78	3	76.2	3.000	4560	7.069	2736	4.241	2417	3.746	1414	2.191	1824	2.827
91	3 1/2	88.9	3.500	6207	9.621	3724	5.773	3290	5.099	1924	2.983	2483	3.848
103	4	101.6	4.000	8107	12.566	4864	7.540	4297	6.660	2513	3.896	3243	5.027

TABLE 19-6 Dimensions and Percent Area of Conduit and Tubing (Areas of Conduit or Tubing for the Combinations of Wires Permitted in Table 1, Chapter 9) (*Continued*)

Articles 352 and 353—Rigid PVC Conduit (RNC), Schedule 40, and HDPE Conduit													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	3/8	—	—	—	—	—	—	—	—	—	—	—	—
16	1/2	15.3	0.602	184	0.285	110	0.171	97	0.151	57	0.088	74	0.114
21	3/4	20.4	0.804	327	0.508	196	0.305	173	0.269	101	0.157	131	0.203
27	1	26.1	1.029	535	0.832	321	0.499	284	0.441	166	0.258	214	0.333
35	1 1/4	34.5	1.360	935	1.453	561	0.872	495	0.770	290	0.450	374	0.581
41	1 1/2	40.4	1.590	1282	1.986	769	1.191	679	1.052	397	0.616	513	0.794
53	2	52.0	2.047	2124	3.291	1274	1.975	1126	1.744	658	1.020	849	1.316
63	2 1/2	62.1	2.445	3029	4.695	1817	2.817	1605	2.488	939	1.455	1212	1.878
78	3	77.3	3.042	4693	7.268	2816	4.361	2487	3.852	1455	2.253	1877	2.907
91	3 1/2	89.4	3.521	6277	9.737	3766	5.842	3327	5.161	1946	3.018	2511	3.895
103	4	101.5	3.998	8091	12.554	4855	7.532	4288	6.654	2508	3.892	3237	5.022
129	5	127.4	5.016	12748	19.761	7649	11.856	6756	10.473	3952	6.126	5099	7.904
155	6	153.2	6.031	18433	28.567	11060	17.140	9770	15.141	5714	8.856	7373	11.427
Article 352—Type A, Rigid PVC Conduit (RNC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
16	1/2	17.8	0.700	249	0.385	149	0.231	132	0.204	77	0.119	100	0.154
21	3/4	23.1	0.910	419	0.650	251	0.390	222	0.345	130	0.202	168	0.260
27	1	29.8	1.175	697	1.084	418	0.651	370	0.575	216	0.336	279	0.434
35	1 1/4	38.1	1.500	1140	1.767	684	1.060	604	0.937	353	0.548	456	0.707
41	1 1/2	43.7	1.720	1500	2.324	900	1.394	795	1.231	465	0.720	600	0.929
53	2	54.7	2.155	2350	3.647	1410	2.188	1245	1.933	728	1.131	940	1.459
63	2 1/2	66.9	2.635	3515	5.453	2109	3.272	1863	2.890	1090	1.690	1406	2.181
78	3	82.0	3.230	5281	8.194	3169	4.916	2799	4.343	1637	2.540	2112	3.278
91	3 1/2	93.7	3.690	6896	10.694	4137	6.416	3655	5.668	2138	3.315	2758	4.278
103	4	106.2	4.180	8858	13.723	5315	8.234	4695	7.273	2746	4.254	3543	5.489
129	5	—	—	—	—	—	—	—	—	—	—	—	—
155	6	—	—	—	—	—	—	—	—	—	—	—	—
Article 352—Type EB, PVC Conduit (RNC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
16	1/2	—	—	—	—	—	—	—	—	—	—	—	—
21	3/4	—	—	—	—	—	—	—	—	—	—	—	—
27	1	—	—	—	—	—	—	—	—	—	—	—	—
35	1 1/4	—	—	—	—	—	—	—	—	—	—	—	—
41	1 1/2	—	—	—	—	—	—	—	—	—	—	—	—
53	2	56.4	2.221	2498	3.874	1499	2.325	1324	2.053	774	1.201	999	1.550
63	2 1/2	—	—	—	—	—	—	—	—	—	—	—	—

(Continued)

TABLE 19-6 Dimensions and Percent Area of Conduit and Tubing (Areas of Conduit or Tubing for the Combinations of Wires Permitted in Table 1, Chapter 9) (*Continued*)

Article 352—Type EB, PVC Conduit (RNC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
78	3	84.6	3.330	5621	8.709	3373	5.226	2979	4.616	1743	2.700	2248	3.484
91	3½	96.6	3.804	7329	11.365	4397	6.819	3884	6.023	2272	3.523	2932	4.546
103	4	108.9	4.289	9314	14.448	5589	8.669	4937	7.657	2887	4.479	3726	5.779
129	5	135.0	5.316	14314	22.195	8588	13.317	7586	11.763	4437	6.881	5726	8.878
155	6	160.9	6.336	20333	31.530	12200	18.918	10776	16.711	6303	9.774	8133	12.612
Article 350—Liquidtight Flexible Metal Conduit (LFMC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	⅜	12.5	0.494	123	0.192	74	0.115	65	0.102	38	0.059	49	0.07
16	½	16.1	0.632	204	0.314	122	0.188	108	0.166	63	0.097	81	0.0
21	¾	21.1	0.830	350	0.541	210	0.325	185	0.287	108	0.168	140	0.0
27	1	26.8	1.054	564	0.873	338	0.524	299	0.462	175	0.270	226	0.0
35	1¼	35.4	1.395	984	1.528	591	0.917	522	0.810	305	0.474	394	0.0
41	1½	40.3	1.588	1276	1.981	765	1.188	676	1.050	395	0.614	510	0.0
53	2	51.6	2.033	2091	3.246	1255	1.948	1108	1.720	648	1.006	836	1.29
63	2½	63.3	2.493	3147	4.881	1888	2.929	1668	2.587	976	1.513	1259	1.95
78	3	78.4	3.085	4827	7.475	2896	4.485	2559	3.962	1497	2.317	1931	2.99
91	3½	89.4	3.520	6277	9.731	3766	5.839	3327	5.158	1946	3.017	2511	3.89
103	4	102.1	4.020	8187	12.692	4912	7.615	4339	6.727	2538	3.935	3275	5.07
129	5	—	—	—	—	—	—	—	—	—	—	—	—
155	6	—	—	—	—	—	—	—	—	—	—	—	—
Article 344—Rigid Metal Conduit (RMC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	⅜	—	—	—	—	—	—	—	—	—	—	—	—
16	½	16.1	0.632	204	0.314	122	0.188	108	0.166	63	0.097	81	0.125
21	¾	21.2	0.836	353	0.549	212	0.329	187	0.291	109	0.170	141	0.220
27	1	27.0	1.063	573	0.887	344	0.532	303	0.470	177	0.275	229	0.355
35	1¼	35.4	1.394	984	1.526	591	0.916	522	0.809	305	0.473	394	0.610
41	1½	41.2	1.624	1333	2.071	800	1.243	707	1.098	413	0.642	533	0.829
53	2	52.9	2.083	2198	3.408	1319	2.045	1165	1.806	681	1.056	879	1.363
63	2½	63.2	2.489	3137	4.866	1882	2.919	1663	2.579	972	1.508	1255	1.946
78	3	78.5	3.090	4840	7.499	2904	4.499	2565	3.974	1500	2.325	1936	3.000
91	3½	90.7	3.570	6461	10.010	3877	6.006	3424	5.305	2003	3.103	2584	4.004
103	4	102.9	4.050	8316	12.882	4990	7.729	4408	6.828	2578	3.994	3326	5.153
129	5	128.9	5.073	13050	20.212	7830	12.127	6916	10.713	4045	6.266	5220	8.085
155	6	154.8	6.093	18821	29.158	11292	17.495	9975	15.454	5834	9.039	7528	11.663

TABLE 19-6 Dimensions and Percent Area of Conduit and Tubing (Areas of Conduit or Tubing for the Combinations of Wires Permitted in Table 1, Chapter 9) (*Continued*)

Article 352—Rigid PVC Conduit (RNC), Schedule 80													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	3/8	—	—	—	—	—	—	—	—	—	—	—	—
16	1/2	13.4	0.526	141	0.217	85	0.130	75	0.115	44	0.067	56	0.087
21	3/4	18.3	0.722	263	0.409	158	0.246	139	0.217	82	0.127	105	0.164
27	1	23.8	0.936	445	0.688	267	0.413	236	0.365	138	0.213	178	0.275
35	1 1/4	31.9	1.255	799	1.237	480	0.742	424	0.656	248	0.383	320	0.495
41	1 1/2	37.5	1.476	1104	1.711	663	1.027	585	0.907	342	0.530	442	0.684
53	2	48.6	1.913	1855	2.874	1113	1.725	983	1.523	575	0.891	742	1.150
63	2 1/2	58.2	2.290	2660	4.119	1596	2.471	1410	2.183	825	1.277	1064	1.647
78	3	72.7	2.864	4151	6.442	2491	3.865	2200	3.414	1287	1.997	1660	2.577
91	3 1/2	84.5	3.326	5608	8.688	3365	5.213	2972	4.605	1738	2.693	2243	3.475
103	4	96.2	3.786	7268	11.258	4361	6.755	3852	5.967	2253	3.490	2907	4.503
129	5	121.1	4.768	11518	17.855	6911	10.713	6105	9.463	3571	5.535	4607	7.142
155	6	145.0	5.709	16513	25.598	9908	15.359	8752	13.567	5119	7.935	6605	10.239
Article 342—Intermediate Metal Conduit (IMC)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	3/8	—	—	—	—	—	—	—	—	—	—	—	—
16	1/2	16.8	0.660	222	0.342	133	0.205	117	0.181	69	0.106	89	0.137
21	3/4	21.9	0.864	377	0.586	226	0.352	200	0.311	117	0.182	151	0.235
27	1	28.1	1.105	620	0.959	372	0.575	329	0.508	192	0.297	248	0.384
35	1 1/4	36.8	1.448	1064	1.647	638	0.988	564	0.873	330	0.510	425	0.659
41	1 1/2	42.7	1.683	1432	2.225	859	1.335	759	1.179	444	0.690	573	0.890
53	2	54.6	2.150	2341	3.630	1405	2.178	1241	1.924	726	1.125	937	1.452
63	2 1/2	64.9	2.557	3308	5.135	1985	3.081	1753	2.722	1026	1.592	1323	2.054
78	3	80.7	3.176	5115	7.922	3069	4.753	2711	4.199	1586	2.456	2046	3.169
91	3 1/2	93.2	3.671	6822	10.584	4093	6.351	3616	5.610	2115	3.281	2729	4.234
103	4	105.4	4.166	8725	13.631	5235	8.179	4624	7.224	2705	4.226	3490	5.452
Article 356—Liquidtight Flexible Nonmetallic Conduit (LFNC-B*)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	3/8	12.5	0.494	123	0.192	74	0.115	65	0.102	38	0.059	49	0.077
16	1/2	16.1	0.632	204	0.314	122	0.188	108	0.166	63	0.097	81	0.125
21	3/4	21.1	0.830	350	0.541	210	0.325	185	0.287	108	0.168	140	0.216
27	1	26.8	1.054	564	0.873	338	0.524	299	0.462	175	0.270	226	0.349
35	1 1/4	35.4	1.395	984	1.528	591	0.917	522	0.810	305	0.474	394	0.611
41	1 1/2	40.3	1.588	1276	1.981	765	1.188	676	1.050	395	0.614	510	0.792
53	2	51.6	2.033	2091	3.246	1255	1.948	1108	1.720	648	1.006	836	1.298

*Corresponds to 356.2(2)

(Continued)

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TABLE 19-6 Dimensions and Percent Area of Conduit and Tubing (Areas of Conduit or Tubing for the Combinations of Wires Permitted in Table 1, Chapter 9) (*Continued*)

Article 356—Liquidtight Flexible Nonmetallic Conduit (LFNC-A*)													
Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²	mm ²	in ²
12	3/8	12.6	0.495	125	0.192	75	0.115	66	0.102	39	0.060	50	0.077
16	1/2	16.0	0.630	201	0.312	121	0.187	107	0.165	62	0.097	80	0.125
21	3/4	21.0	0.825	346	0.535	208	0.321	184	0.283	107	0.166	139	0.214
27	1	26.5	1.043	552	0.854	331	0.513	292	0.453	171	0.265	221	0.342
35	1 1/4	35.1	1.383	968	1.502	581	0.901	513	0.796	300	0.466	387	0.601
41	1 1/2	40.7	1.603	1301	2.018	781	1.211	690	1.070	403	0.626	520	0.807
53	2	52.4	2.063	2157	3.343	1294	2.006	1143	1.772	669	1.036	863	1.337

*Corresponds to 356.2(1)

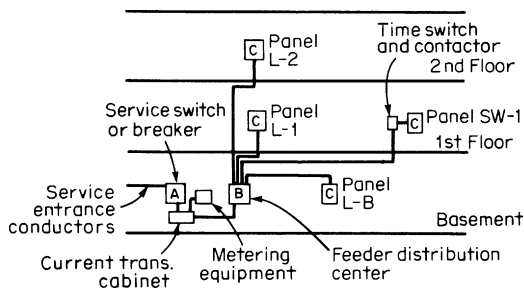
The number of conductors in one conduit or tubing is another important factor. The number of conductors of a certain size that may be installed in a given-sized conduit or EMT is limited to provide for ready installation and withdrawal without injury to conductor or insulating covering. Table 19-3 gives these values for commonly used conductors.

In considering the ampacity of conductors and conduit fill, it is important to note that derating of ampacity applies for increased ambient temperatures and for more than three conductors, excluding neutrals, in a conduit.

Flexible cords and fixture wire in some cases may be as small as No. 18 AWG; hence these are exceptions to the general rule that no conductor smaller than No. 14 should be used in light and power wiring. Owing to the heat generated in the lamp, heat-resistant wiring is required in fixtures.

19.4 TYPES OF CIRCUIT

Services and Feeders. No limit is placed on the electrical capacity of service conductors and service protection employed in bringing the electric supply into a building, since only one supply should be

**FIGURE 19-10** Riser diagram showing location of A—service, B—feeder, and C—branch circuit overcurrent protective devices.

introduced whenever possible. Near the point of entrance of the supply, the heavy-service conductors are tapped by feeders, which conduct the electricity to panelboards at various load centers in the building, where the final branch circuits which supply individual lighting, heating, and power outlets originate (see Fig. 19-10). No limits are placed on the electrical capacity of feeders, but for practical purposes they are limited in size by the difficulty of handling large conductors and raceways in restricted building spaces, by voltage drop, and by economic considerations.

TABLE 19-7 Summary of Branch-Circuit Requirements

Circuit Rating	15 A	20 A	30 A	40A	50 A
Conductors (min. size):					
Circuit wires*	14	12	10	8	6
Taps	14	14	14	12	12
Fixture wires and cords—see	240.5				
Overcurrent Protection	15A	20 A	30 A	40A	50 A
Outlet device:					
Lampholders permitted	Any type	Any type	Heavy duty	Heavy duty	Heavy duty
Receptacle rating†	15 max. A	15 or 20 A	30 A	40 or 50 A	50 A
Maximum Load	15A	20 A	30 A	40A	50 A
Permissible load	See 210.23(A)	See 210.23(A)	See 210.23(B)	See 210.23(C)	See 210.23(C)

*These gauges are for copper conductors.

†For receptacle rating of cord-connected electric-discharge luminaires (lighting fixtures), see NEC Section 410.30(C).

Each lighting fixture, motor, heating device, or other item of utilization equipment must be supplied by one of the types of branch circuit.

Branch Circuits for Grouped Loads. The uses and limitations of the common types of branch circuit are outlined in Table 19-7. It will be noted that lighting branch circuits may carry loads as high as 50 A, although fluorescent lighting is limited to use on circuits of 15- or 20-A rating. Such circuits are extensively employed in commercial and industrial occupancies. Branch circuits supplying convenience outlets for general use in other than manufacturing areas are usually limited to a maximum of 20 A, as the type of outlet required for heavier-capacity circuits usually will not accommodate the connection plug found on portable cords or lamps, motor-driven office machinery, etc.

Individual Branch Circuits. Any individual piece of equipment (except motors) may also be connected to a branch circuit meeting the following requirements: conductors must be large enough for the individual load supplied. Overcurrent protection must not exceed the capacity of the conductors or 150% of the rating of the individual load, if the single load device is a non-motor-operated appliance rated at 13.3 A or more. Only a single outlet or piece of equipment may be supplied.

Motor Branch Circuits. Owing to the peculiar conditions obtained during the starting period of a motor, and because it may be subjected to severe overloads at frequent intervals, motors, except for very small sizes, are connected to branch circuits of a somewhat different design from that previously discussed.

19.5 OVERCURRENT PROTECTION

Molded-Case Circuit Breakers. A circuit breaker is defined by the NEC as “a device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its ratings.” In addition, the purpose of a circuit breaker (Fig. 19-11), as stated in the NEC, is to open the circuit if the current reaches a value that will cause an excessive or dangerous temperature in a conductor or its insulation.



FIGURE 19-11 Typical molded-case circuit breakers.

Underwriters' Laboratories (UL) Standard UL489, *Molded Case Circuit Breakers and Circuit Breaker Enclosures*, further specifies test and construction requirements for molded-case circuit breakers specifically intended to provide service entrance and feeder and branch circuit protection in accordance with the NEC. These UL requirements cover molded-case circuit breakers rated through 600 V. Underwriter's Laboratories specifies the applicable standards to which the circuit breaker is designed, whereas the NEC discusses proper applications of circuit breakers.

Ratings. The ratings which apply to circuit breakers and their actual assigned numerical values reflect mechanical, electrical, and thermal capabilities of those circuit breakers that comply with industry standards published by the National Electrical Manufacturers Association and UL. These ratings, which appear on the breaker, include the following:

1. **Voltage.** Circuit breakers are designed and marked with the maximum voltage at which they can be applied. They can be used on any system where the voltage is lower than this breaker rating. This includes both ac and dc voltage systems.
2. **Frequency.** Circuit breakers are normally suitable for use on 50- and 60-Hz electrical distribution systems. Rerating of the circuit breaker may be required at other frequencies.
3. **Continuous current.** Standard molded-case circuit breakers are calibrated to carry 100% of their rated current in free air at 40°C ambient. In accordance with the NEC, when installed in their enclosures, these breakers should not be continuously loaded over 80% of their current rating. However, there are certain molded-case circuit breakers specifically approved for 100% continuous rating available, and these are so marked.
4. **Current interrupting.** The current-interrupting rating is expressed in rms symmetrical amperes. It may vary with the applied voltage and is the maximum current the breaker can be expected to safely interrupt. These current-interrupting ratings may vary from 1500 through 200,000 A, depending upon applied voltage. Underwriter's Laboratory requires all circuit breakers to be so marked with their proper ratings.

Thermal-Magnetic Circuit Breakers. Thermal-magnetic circuit breakers provide two forms of overcurrent protection. The first is overload protection, which is achieved by a bimetal providing an inverse time-current response. The second is overcurrent protection, which is achieved magnetically.

Overload tripping is obtained through deflection of the bimetal, which is heated by the load current. During an overload condition, the bimetal deflects, causing the breaker to trip or open mechanically. The larger the overload, the faster the tripping of the circuit breaker; the smaller the overload, the longer it takes the circuit breaker to trip. This is commonly called an *inverse-time principle*.

Overcurrent (short circuit) protection is obtained through electromagnetic tripping action without any intentional time delay. An overcurrent condition must be interrupted rapidly (usually less than 20 ms) in order to protect downstream equipment. During overcurrent conditions, an armature is moved by electromagnetic force and initiates tripping action.

All circuit breakers are rated for continuous current. This continuous-current rating is dependent upon the maximum current the load is expected to draw for 3 h or more continuously. Ratings may be fixed or adjustable, depending on the circuit breaker. Some constructions may require replacing all or part of the trip unit to change the continuous current rating. Overcurrent trip characteristics are a function, multiple, or percentage of the continuous-current rating.

Current-Limiting Circuit Breakers.

The NEC defines a current-limiting overcurrent protective device as “a device which, when interrupting current in its current limiting range, will reduce the current flow in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance.”

Additionally, UL has the following current-limiting circuit-breaker definition: “a circuit breaker that does not employ a fusible element and that when operating within its current-limiting range, limits the let-through I^2 to a value less than the I^2 of a $1/2$ cycle wave of the symmetrical prospective current.”

Current-limiting circuit breakers (Fig. 19-12) not only provide high interrupting capability but also limit let-through current and energy to downstream devices. I^2t is an expression related to the energy resulting from current flow. Specific manufacturer’s literature should be consulted for information on the current-limiting and energy-limiting characteristics of their particular circuit breakers.

Current-limiting circuit breakers provide the system designer with a means of reducing fault current and energy levels at downstream system components while still retaining the advantages, such as common trip and reusability, of circuit breaker protection. Current-limiting breakers can be reset and service restored in the same manner as conventional thermal-magnetic circuit breakers. There is nothing to replace even after clearing maximum fault currents. Figure 19-13 illustrates the current waveform resulting from current-limiting operation. At current levels below the threshold of current limitation, conventional non-current-limiting operation is the same as described for thermal-magnetic circuit breakers.

Solid-State Trip Circuit Breakers. Solid-state trip circuit breakers utilize solid-state electronic components to measure and time the output from current transformers. The solid-state circuitry then initiates tripping action based on predetermined settings. These components are housed in the trip unit section of the breaker.

The basic function of the trip unit is to provide long-time current-time delay and instantaneous current response characteristics necessary for proper circuit protection. Combinations of these characteristics provide time delay to override transient overload, delayed tripping for sustained overloads, and instantaneous tripping for high-level short circuits.



FIGURE 19-12 Current-limiting circuit breaker.

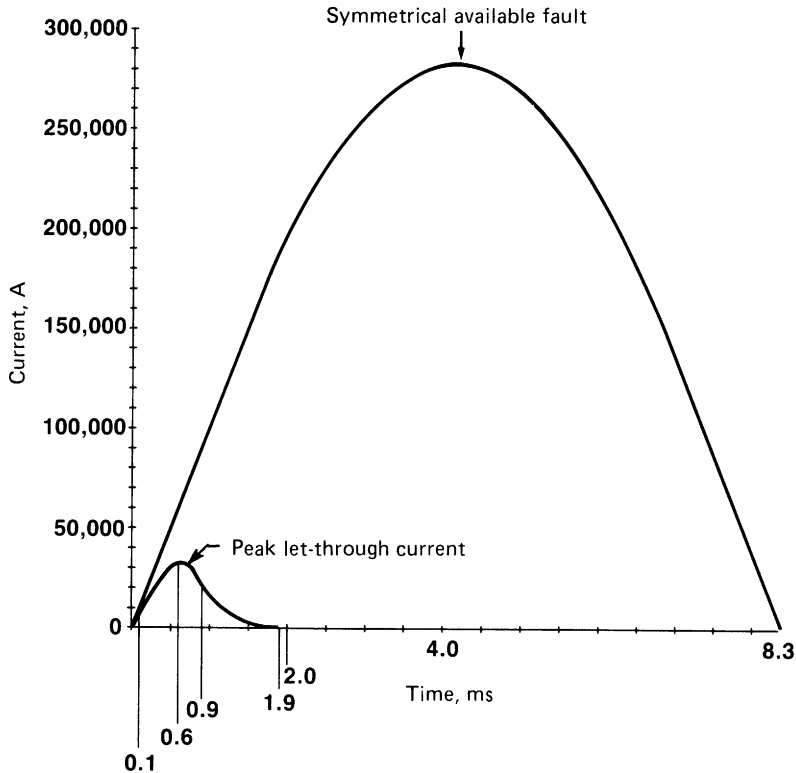


FIGURE 19-13 Time-current curve for a current-limiting breaker.

Solid-state trip units may also be equipped with short-time pickup and delay functions. These characteristics are useful for providing coordination with downstream or upstream circuit breakers and/or fuses. The resulting combination of long- and short-time delay characteristics provide delayed tripping for all levels of overcurrent below the instantaneous response. This provides time for downstream breakers to operate and clear the fault.

Solid-state trip units may also provide time-current characteristics for equipment ground fault protection in accordance with the NEC Sec. 230-95 requirements. The maximum current setting is 1200 A per NEC requirements, and time-delay settings are usually adjustable to permit coordination with other protective devices.

Time-Current Characteristic Curves. Circuit breaker time-current characteristic curves are a function of the type of trip function and its associated settings. A typical time-current characteristic curve is shown in Fig. 19-14 for a 400-A frame thermal-magnetic molded-case circuit breaker.

This particular curve applies for the continuous-current rating of 400 A and indicates total operational time from fault current initiation to clearing. This is a typical characteristic curve for a molded-case circuit breaker where overload sensing is achieved through a thermal element (a bimetal) and where instantaneous tripping is achieved magnetically.

In circuit-breaker frame sizes larger than 100 A, instantaneous operation is adjustable within approximately 5 to 10 times the continuous ampere rating.

Molded-case circuit breakers with more complex time-current characteristics are usually equipped with solid-state trip units. The continuous current rating may be adjustable using the long-time pickup function. In addition, long-time delay and short-time pickup and delay functions may be adjustable. The instantaneous response may also be adjustable.

Circuit breakers with solid-state trip units may also include integral equipment ground fault protection with current pickup and time-delay adjustments. Figure 19-15 illustrates a combined time-current characteristic curve for a solid-state electronic trip circuit breaker with all of these adjustments.

Further refinement of the solid-state trip unit short-time delay characteristics for overcurrent protection or the ground fault time-delay characteristics may be obtained by making part of the response curve a function of the product of time and the square of current (I^2t) illustrated by the sloping portions in Fig. 19-16. This sloping response curve often more readily coordinates with upstream or downstream thermal-magnetic circuit breakers and/or fuses.

It should be noted that solid-state trip units are available with varying degrees of complexity, and not all functions are provided for most applications. The specific manufacturer's literature should be consulted for guidance on individual units.

Series-Connected Ratings. *Series connection* of molded-case circuit breakers is a viable protection scheme, provided testing has verified performance. Underwriter's Laboratory presently recognizes series-connected short-circuit ratings and specifies test procedures to verify performance. Series-connected ratings must be based on tests and are only valid for specific circuit breaker types listed in the UL test reports. Individual manufacturer's series-connected ratings may be found in the *UL Recognized Component Directory*. Fuse-breaker coordinated combinations are also tested by UL and are applicable within their established guidelines.

Coordination. When protection is being considered, the performance of a circuit breaker with respect to the connected

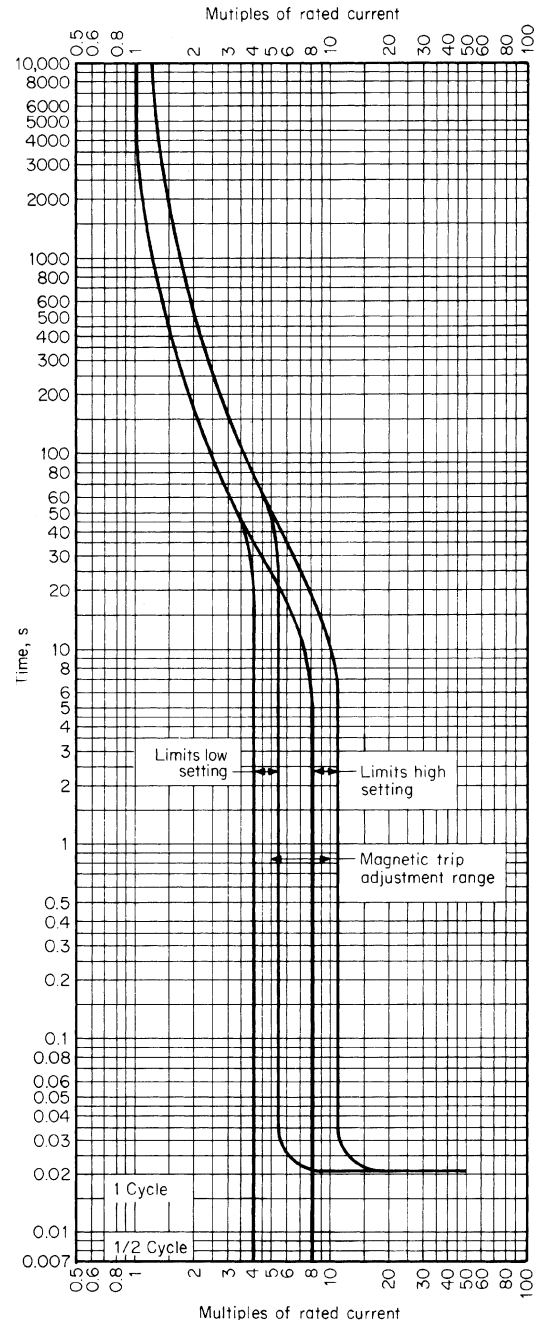


FIGURE 19-14 Characteristic tripping curve for molded-case breaker.

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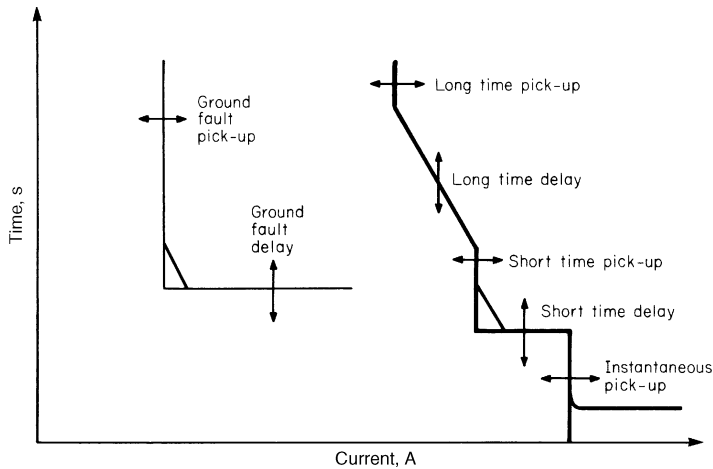


FIGURE 19-15 Time-current curve for solid-state electronic breaker.

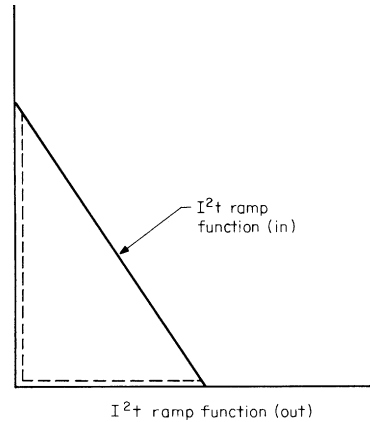


FIGURE 19-16 Sloping response curve for coordinating with thermal magnetic breakers or fuses.

conductors and load is a primary concern. Consideration is also given to the performance of circuit breakers with respect to other upstream and downstream circuit breakers and other protective devices. The object in coordinating protective devices is to make them selective in their operation with respect to each other. In doing so, the effects of short circuits on systems are reduced to a minimum by disconnecting only the affected parts of a system. Stated in another way, only the circuit breaker nearest the short circuit should open, leaving the rest of the system intact and able to supply power to the unaffected areas.

19.6 LOW-VOLTAGE BUSWAY

Low-Voltage Busways. Low-voltage busway (Fig. 19-17) provides a convenient, economical means of power distribution for a wide range of industrial and commercial buildings.

Description. Low-voltage (600 V and below) busways consist of a factory prefabricated housing which encloses current-carrying busbars. The housing protects the busbars from physical harm and provides mechanical support. Busbars, which are normally electroplated and insulated, may be either aluminum or copper.

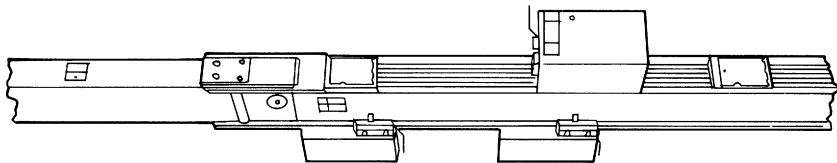


FIGURE 19-17 Low-voltage busway.

Types. Busway uses encompass a wide range of applications. For this reason, various types of busways have evolved. For medium- and high-current applications (100 to 5000 A), low-impedance *feeder* busway and *plug-in* busway are available. These types of busway are utilized to supply and/or distribute large blocks of power within a factory or office building. *Lighting* bus and *trolley* duct normally supply power to small lighting loads or moving loads such as hand tools on an assembly line. This type bus is rated 30 to 100 A.

Feeder busway is designed to provide maximum efficiency of power transfer from one point to another. If multiple-power tap-off points are required, then a plug-in busway is utilized. Plug-in busway is similar to a feeder busway except that plug-in openings are located at convenient intervals along the entire length. Various types of fusible or circuit breaker plug-in units may be easily attached at these openings to supply power to individual loads. Lighting contactors, motor starters, and other specialized devices are also available in plug-in unit form.

Applications. Busway uses are many and varied. However, they may be grouped into four major categories: (1) the main service busway, (2) the long feeder busway run, (3) the plug-in busway distribution, and (4) the electrical riser for tall buildings.

The *main service busway* is usually a fairly short run of high-ampere feeder busway which brings electricity from the power company supply point into the main switchboard in a building.

Long feeder busway runs are designed to carry large blocks of electrical power from one point to another with maximum efficiency. A typical example of this type of application would be a busway used to bring power from the main service switchboard to a remote distribution switchboard.

Plug-in busway distribution is the normal method for power distribution in most modern manufacturing areas today. The plug-in busway is positioned throughout the manufacturing area, and loads are connected to the busway using fusible or circuit breaker plug-in units. This wiring method is flexible and allows for the addition or movement of loads simply by relocating the plug-in units which attach to the busway.

Finally, *electrical busway risers* are used to form the backbone of the power distribution system in tall metropolitan buildings. The busway is positioned vertically within the building and tap-offs are used on each floor to provide the necessary power requirements. As load requirements increase in the future, the busway riser can be preplanned to allow for additional tap-offs, thus continuing to grow with the building.

Ratings. Low-voltage busway is available for applications up to 600 V ac and may be supplied for use on 3-phase, 3- or 4-wire systems. A wide range of feeder or plug-in busway ampere ratings may be selected (see Table 19-8). These ratings are based on actual heat rise within the busway. Current standards limit the maximum “hot-spot” temperature within the busway housing to 55°C above ambient.

Ground Bus. A busway with a separate, low-impedance ground conductor is also available to provide for (1) a low-level static ground path, and (2) a secure low-impedance ground return path for medium- and high-level ground faults. This ground conductor is generally bonded to the busway housing at intervals of 10 ft or less. It is designed to carry a continuous 50% ground fault current as well as high-level ground fault currents of a short duration.

Conductors. A busway can be supplied with either aluminum or copper conductors. Based on size considerations only, copper is a more efficient electrical conductor than aluminum. However, when actual cost is considered, aluminum conductors are favored even though they must be slightly larger than the copper conductor required for the same ampere rating. Both aluminum and copper

TABLE 19-8 Low-Voltage Busway—Ampere Ratings

Plug-in		Feeder
████	225 A	
████	400 A	
████	600 A	
████	800 A	████
████	1000 A	████
████	1200 A	████
████	1350 A	████
████	1600 A	████
████	2000 A	████
████	2500 A	████
████	3000 A	████
████	4000 A	████
	5000 A	████

TABLE 19-9 Low-Voltage Busway Short-Circuit Ratings

Continuous-Current rating of busway, A		Minimum short-circuit current ratings, A
Plug-in	Feeder	Symmetrical
100	...	10,000
225	...	14,000
400	...	22,000
600	...	22,000
	600	42,000
800	...	22,000
	800	42,000
1000	...	42,000
	1000	75,000
1200	...	42,000
1350	...	42,000
	1200	75,000
	1350	75,000
1600	...	65,000
	1600	100,000
2000	...	65,000
	2000	100,000
2500	...	65,000
	2500	150,000
3000	...	85,000
	3000	150,000
4000	...	85,000
	4000	200,000
	5000	200,000

conductors are electroplated using tin or silver to ensure good surface conductivity at all electrical joints and plug-in unit connection points.

Available Fault Current Levels. In order to ensure that a busway can safely withstand the extreme physical forces, which can occur during a high-level fault, tests are conducted and maximum short-circuit levels are assigned to all busway components. The industry-recommended minimum short-circuit ratings for feeder and plug-in busway are shown in Table 19-9. In some instances optional higher short-circuit levels are available using alternate construction methods.

The actual available fault current throughout the entire electrical distribution system should be determined to ensure that all system components will function safely if a fault should occur.

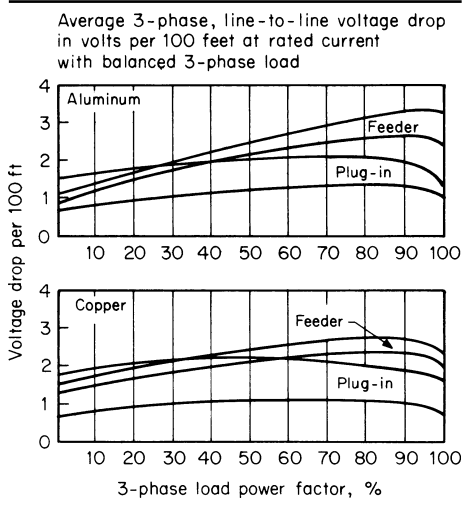
Voltage Drop. Excessively low-voltage or wide-voltage variations on an electrical system can create many operating problems for the user. Modern low-impedance busway is designed to introduce an absolute minimum amount of voltage drop into the electrical system, thus helping to provide a stable source of electrical

power. Typical feeder and plug-in busway voltage drop curves are shown in Table 19-10. Individual busway manufacturers can provide exact voltage drop curves for the specific busway

ratings and types involved in each individual application.

Installation. A low-voltage busway system is made up of individual, factory-prefabricated components such as 10-ft straight lengths, elbows, tees, flanged ends, and cable tap boxes. These individual components are designed so they can be quickly joined together at the job site with a minimum of field labor. Typically, one grade-5 bolt and two large-diameter Belleville washers are utilized to connect all the bars in an entire bus stack (see Fig. 19-18). In some cases, special joint bolts are supplied with heads that pop off when torqued to the proper level, resulting in a tight connection. Larger ampere ratings may utilize two or three busbar stacks, which may require slight additional assembly time.

Prefabricated busway components reduce actual installation time to a minimum and result in a very low *installed cost* for the low-voltage busway. (The installed cost is the total material and labor cost necessary to provide a completed busway installation.)

TABLE 19-10 Typical Feeder and Plug-in Busway Voltage Drop Curves

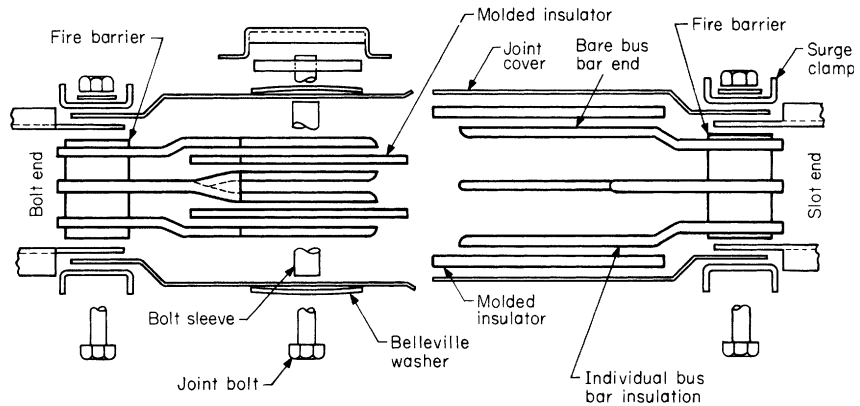


FIGURE 19-18 Busway one-bolt joint.

19.7 PROTECTIVE GROUNDING

Purpose of Grounding. Secondary ac distribution systems should be grounded at the neutral conductor if the maximum voltage to ground does not exceed 150 V and may be grounded if this voltage is above 150 but does not exceed 300 V (Fig. 19-19). This is to guard against imposition of a dangerous high voltage in case a breakdown in the transformer or crossing of primary- and secondary-circuit wires occurs.

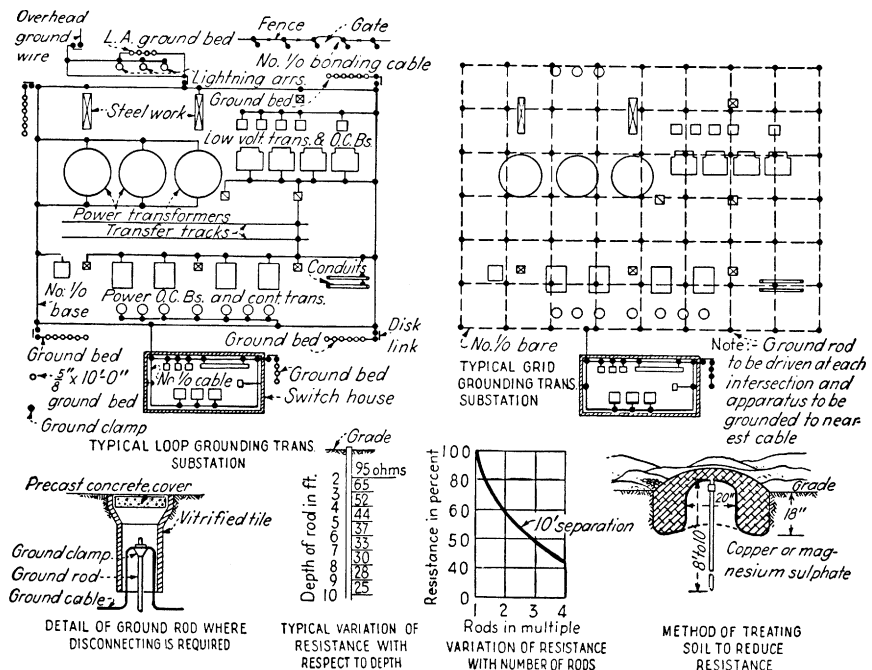


FIGURE 19-19 Complex equipment-grounding details showing connection, wire sizes, and grounds.

Conduits, metal raceways, cable armors, and metal cases or frames of equipment must be grounded (or isolated, as an alternative) and bonded so that, if this metal enclosure should come into contact with any of the circuit wires within it, no dangerous current would be passed to a person who touched the enclosure, since it is kept at ground potential.

The path to ground must be sufficiently low in resistance to allow enough current to flow to quickly open an overcurrent protective device and clear the fault. Otherwise, a voltage buildup will occur on metallic parts, with consequent hazards.

Size and Location of Ground Connection. The service neutral should be grounded at the point of entrance ahead of any disconnecting equipment with a copper wire or bus not smaller than indicated in Table 19-11. The neutral cannot be grounded at points beyond the load side of the disconnecting means (see NEC Article 250.24(A)(5)).

Metallic enclosures are commonly grounded through the grounding conductor used for the service neutral, although conduit or electrical metallic tubing may be used.

The grounding connection should be made to a grounding electrode such as (1) a metal underground water pipe, (2) a metal frame of a building, (3) concrete encased electrode, (4) a ground ring,

TABLE 19-11 Grounding Electrode Conductor for Alternating-Current Systems

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors* (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum†
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Notes:

1. Where multiple sets of service-entrance conductors are used as permitted in NEC 230.40, exception no. 2, the equivalent size of the largest service-entrance conductor shall be determined by the largest sum of the areas of the corresponding conductors of each set.

2. Where there are no service-entrance conductors, the grounding electrode conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.

*This table also applies to the derived conductors of separately derived ac systems.

†See installation restrictions in NEC 250.64(A).

(5) rod or pipe electrode or, (6) a plate electrode. See NEC Article 250.52. Where each type of electrode is present, they must be bonded together. See NEC Article 250.50. Resistance of a continuous underground water-piping system will usually be less than $0.1\ \Omega$, thereby ensuring effectiveness.

Polarization of Wiring. The conductor to be grounded must be continuously identified throughout the system to avoid errors in connections. For No. 6 AWG or smaller, this is accomplished by finishing the insulating covering with a white or natural-gray finish. Ends of conductors larger than No. 6 AWG are painted white or gray or wrapped with white tape, where exposed in outlets or panelboards.

19.8 SYSTEMS OF INTERIOR DISTRIBUTION

Standard Secondary-Voltage Types. Common interior distribution systems for buildings or plants having appreciable loads are

1. 3-Phase 4-wire 120/208-V serving power and lighting.
2. Single-phase 3-wire 115/230-V serving lighting with 3-phase 3-wire 240- or 480-V for power.
3. 3-Phase 4-wire 277/480-V serving power and fluorescent or mercury lighting with single-phase 115/230-V circuits for other utilization provided from the power system by means of local dry-type transformers.

For very large buildings and industrial plants, distribution is often provided at higher voltage, notably 13.2, 4.1, or 2.3 kV, stepped down to utilization voltage at strategically load-centered substations.

3-Wire Single-Phase Systems. The 3-wire 115/230-V single-phase system (Fig. 19-20) is very commonly used for interior wiring for lighting and miscellaneous purposes but not for motor loads much in excess of 5 hp. The neutral wire is grounded; hence it should not be fused at any point. The branch circuits may be 2-wire 115- or 230-V or 3-wire 115/230-V. The neutral conductor carries only the unbalance in load between the two ungrounded conductors. For circuits up to 200 A, it should have the same capacity as the ungrounded conductors. A factor of 0.7 may be applied to unbalanced loads above 200 A in determining its size.

3-Phase 3-Wire Systems. These are usually employed where motors form a substantial load and where lighting is supplied from a separate single-phase system or by transformer. The usual voltage is 240 or 480 V. Branch circuits may be either 2-wire single-phase or 3-wire 3-phase.

3-Phase 4-Wire Systems. The 3-phase 4-wire system (Fig. 19-21) is widely used. Branch lighting circuits are connected between any one of the phase wires and the neutral wire. Power is taken from the 3-phase wires. The neutral wire is grounded. The voltage between phase wires is usually 208 V, and between any phase wire and neutral it is 120 V.

Circuits that may be supplied include 2-wire 120- or 208-V; 3-wire 120/208- or 208-V; and 4-wire 120/208-V. In the case of a 3-wire circuit consisting of 2-phase wires and the neutral, the “neutral” differs from that of a 3-wire single-phase circuit in that with both sides of the circuit evenly loaded it will carry equal current in the phase wires.

2-Wire Systems. The 2-wire system is used where current is supplied at 115 V, as when obtained from a 115-V generator, and on installations connected to utility companies’ lines when the installation is of small capacity. It is limited in capacity; requires excessively large copper for heavy loads; and, in general, is not considered a modern complete distribution method.

2- and 3-Wire DC Systems. These systems are similar in connections (except grounding on the premises) and use to the 2- and 3-wire single-phase ac systems.

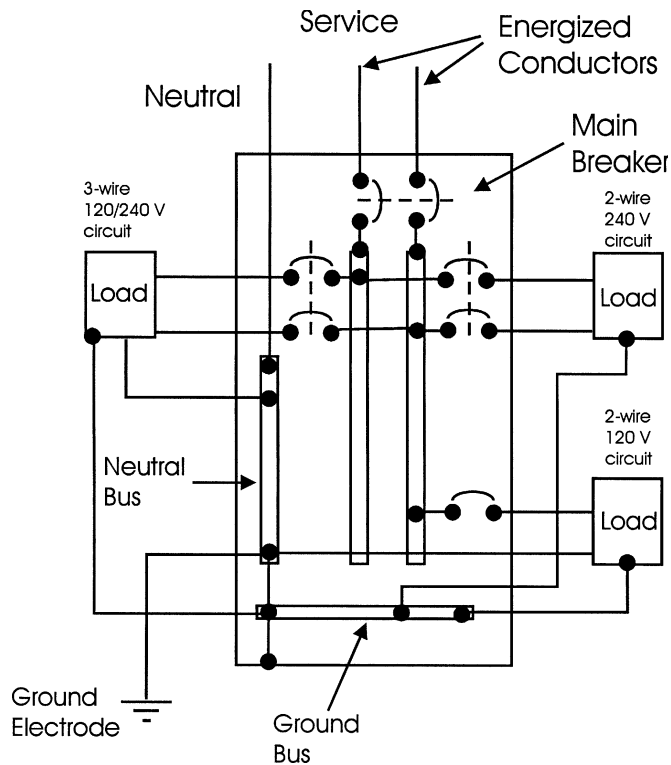


FIGURE 19-20 A 3-wire, 115/230-V, single-phase system.

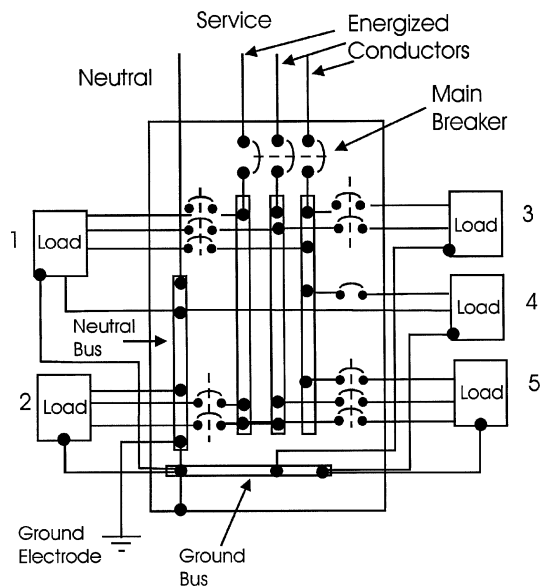


FIGURE 19-21 A 3-phase, 4-wire system: (1) 4-wire 120/208-V circuit; (2) 3-wire 120/208-V circuit; (3) 2-wire 208-V circuit; (4) 2-wire 120-V circuit; (5) 3-wire 208-V circuit.

2-Phase Distribution. This may be effected with 4 or 3 wires. In the former case, there is a pair of wires for each phase, while in the latter there is 1 wire for each phase and a common wire for both phases. The circuits must be balanced on either side, just as in the case of a 3-wire single-phase system. Where 3 wires are used, the common wire should be 1.4 times as large as either of the other two, since it must carry 1.4 times as much current. Motors are connected to both phases and employ all 3 or all 4 wires, as the case may be. With 4 wires, the lamps are connected to each phase as though the supply were single-phase, and care should be exercised to balance the phases as nearly as possible.

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